Crop identification and area estimation through the combined use of satellite and field data for county Durham, northern England

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بسم الله الرحمن الرحيم

Crop Identification and Area Estimation Through the Combined Use of Satellite and Field Data for County Durham, Northern England

by

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A thesis presented for the degree of Doctor of Philosophy at the University of Durham.

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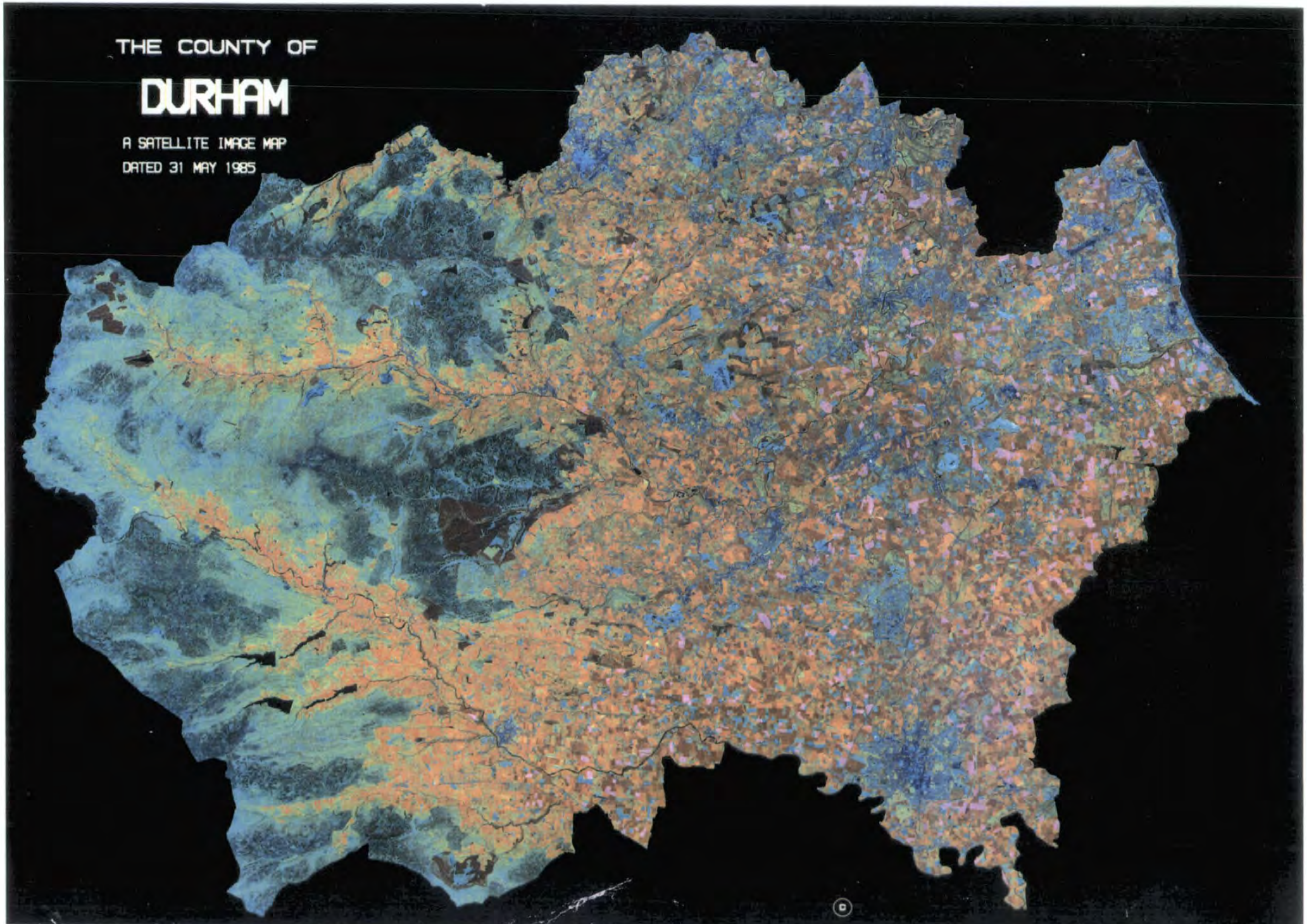
To the memory of my beloved Father SABER SHUEB SALEH

Also to my mother, my daughter Sarah, my sons Waeil and Ihab, my sister Maryam , my brothers and to all my family.

A Landsat-TM Enhanced Colour Composite of County Durham, Northern England. The data was obtained by Landsat-5 on May 31 1985. This EFCC print has been produced by using bands 3(0.63 - 0.69μm), 4(0.76 - 0.90μm)and 5 (1.55 - 1.75μm). The print was also produced at 1 : 50,000 scale for use in this study.


THE COUNTY OF
DURHAM
A SATELLITE IMAGE MAP
DATED 31 MAY 1985
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DECLARATION

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ABSTRACT

This thesis investigates the use of combined field and satellite data for crop identification and area estimation in County Durham, Northeast England.

The satellite data were obtained by the Thematic Mapper (TM) sensor onboard Landsat-5 on 31 May 1985. The TM data were geometrically corrected to the British National Grid and the county boundaries were digitized in order to apply the methodology used in this study on a county basis. The field data were obtained by applying a stratified random sampling strategy. The area was subdivided into five main strata and forty four $1km^2$ sample units were randomly chosen and fully surveyed by the author using a pre-prepared questionnaire. The field area measurements were taken and the final hectarage estimates were obtained for each crop.

The research demonstrated the ability of Landsat-TM data to discriminate between agricultural crops in the study area. Results obtained emphasised that satellite data can be used for identification of agricultural crops over large geographic areas with small field sizes and different environmental and physical features.

A land-cover classification system appropriate to the study area was designed. Using the Landsat-TM data, the study produced a classification map of thirteen land-cover types with more than 80% accuracy. The classification accuracy was assessed quantitatively by using the known land-use information obtained from the sample units visited during the field survey.

The study analysed the factors which influenced the degree of separability between different agricultural crops since some crops were more clearly identified than others.

Using a double sampling method based on the combination of both Landsat-TM and field data in regression analysis, a hectarage estimate was produced for each crop type in County Durham. The results obtained showed that the regression estimator was always more efficient than the field estimator. Crop area estimated by regression reduced the imprecision in all strata and was more efficient in some strata than others. This indicated that a gain in precision was achieved by using Landsat-TM in conjunction with the field data.

The results illustrated that stratification based on an environmental criterion was an efficient approach as far as the the application of agricultural remote sensing in County Durham is concerned. The stratified approach allowed each stratum to be analysed separately, thereby lessening the reliance on cloud free imagery for the whole county on any given date.

Furthermore, the results obtained by this study suggest that it is possibile to link remote sensing data with existing county based information systems on agricultural and land-use.

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GLOSSARY

AgRISTARS	Agriculture and Resource Inventory Through Aerospace Remote Sensing
AID	Agency for International Aid
AP	Aerial Photography
ATS	Application Technology Satellite
CAP	Common Agricultural Policy of EEC
CBH	Cooperation of Bulk Handling
CCT	Computer Compatible Tape
CITARS	Crop Identification Technology Assessment of Remote Sensing
cm	Centimetre
CP	Conservation and Pollution
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CV	Coefficient of Variation
DCLC	Domestic Crops and Land Cover
DIP	Digital Image Processing
DoE	Department of Environment.
DUTA	Determinazione e Utilizzo di Telerilevamenti in Agricoltura
EEC	European Economic Community
EFCC	Enhanced False Colour Composite
EOSAT	Earth Observation Satellite Corporation
ERIM	Environmental Research Institute of Michigan, USA
ERSAC	Environmental Remote Sensing Application Company
ERTS	Earth Resources Technology Satellite, renamed Landsat.
ESA	European Space Agency
EW/CCA	Early Warning and Crop Condition Assessment
FAO	Food and Agriculture Organisation (UN)
FCPF	Foreign Commodity Production Forecasting Project
Fig.	Figure
ft.	Feet

GCP	Ground Control Point
GEMS	An Image Processing System
GIS	Geographical Information System
GLAI	Green Leaf Area Index
I^2S	International Imaging System
IEEE	Institute of Electrical and Electronic Engineering
IFOV	Instantaneous Field of View
INPE	Brazilian Institute for Space Research
ISPRS	International Society for Photogrametry and Remote Sensing
ITD	Inventory Technology Development
JRC	Joint Research Centre (Ispra, Italy) of EEC
km	Kilometre
LACIE	Large Area Crop Inventory Experiment
LAI	Leaf Area Index
Landsat	A Series of Satellites Launched Since 1972
MAFF	Ministry of Agriculture, Fisheries and Food
MIR	Middle Infrared
MP	Managed Pastures
MSS	Multispectral Scanner, on Landsat 1-5
NASA	National Aeronautics and Space Administration
NERC	National Environment Research Council
NGPS	National Gizetteer Pilot Study
NIR	Near Infrared
NLUC	National Land Use Classification
NOAA	National Oceanic and Atmospheric Administration
Noaa	NOAA Satellite
NRSC	National Remote Sensing Centre, Farnborough, U.K.
OS	Ordnance Survey
OSR	Oilseed Rape
P	Pastures

Pixel	Picture Element
r^2	Coefficient of determination
RBV	Return Beam Vidicon, on Landsats 1-3
RE	Relative Efficiency
RG	Managed Pastures
RMS	Root Mean Square Error
RRI	Renewable Resources Inventory
SE	Standard Error
SLUS	Second Land Utilisation Survey
SM	Soil Moisture
SPOT	Satellite Probatoire d'Observation de la Terre
SR	Supporting Research
SRS	Statistical Reporting Service
SU	Sample Unit
SWIR	Short Wave Infrared
TDRSS	Tracking and Data Relay Satellite System
TM	Thematic Mapper on Landsats 4 and 5
USDA	United States Department of Agriculture
USDC	United States Department of Commerce
USDI	United States Department of Interior
USGS	United States Geological Survey
Var	the Variance
VDU	Visual Display unit
WB	Winter Barley
WLSU	World Land Use Survey
WW	Winter Wheat
x	Landsat Area Measurement (ha)
y	Field Area Measurement (ha)
YMD	Yield Model Development

CHAPTER 1

I N T R O D U C T I O N

1.1. SATELLITE REMOTE SENSING FOR AGRICULTURAL APPLICATIONS

Due to the increasing pressure on the land resources and the increasing demand for food to meet current and future needs, decision makers require rapid and accurate methods for monitoring natural resources. Remote sensing is one of the effective monitoring techniques which can be applied in order that existing natural resources be managed more efficiently to meet the high growth level of the world's population.

Remote sensing is an effective tool for gathering data about existing natural resources and it has been applied widely to the problem of monitoring and forecasting agricultural resources. A large amount of statistical information is collected at local, regional, national and international levels about agricultural crops and land use. This study describes important developments in collecting part of this data from satellite imagery and presents a case study at a regional level, that of County Durham in the UK. The principal reasons for the adoption of remote sensing techniques for deriving agricultural statistics are :-

i. The lack of up to date and accurate agricultural information for many parts of the world. This can be a major obstacle to the economic development of a particular country or region (Park *et al* 1980).

ii. Worldwide food production estimates need to be provided regularly and accurately (MacDonald and Hall 1978), since agriculture is the main source of the world's food supply.

iii. Agriculture, unlike any other primary production sector, is dependent upon accurate climatic information.

iv. The need for accurate, comprehensive and up to date information on crop as well as land productivity.

v. The ability of a country (or a region) to produce accurate up to date forecasts of the harvest of major crops coupled with the ability to analyse its position with respect to the current world markets. This may enable its agricultural planners to make economically rewarding export-import decisions (Park *et al* 1980).

To operate efficiently, effectively and profitably, agricultural decision makers need accurate and timely information about production, supplies, prices, exports, weather and other inputs (Mergerson 1982). The analysis of images of the earth has proved to be one of the most cost effective tools for gathering data about agricultural production. Satellite remote sensing techniques may be preferred to aerial photography where large geographic areas must be surveyed.

The interpretation of remotely sensed imagery of crops and soils is difficult due to of the dynamic nature and inherent complexity of biological materials and soils. However, remote sensing technology offers numerous advantages over traditional methods of conducting agricultural and other resource surveys (Myers 1983). One of the main advantages over traditional methods is the ability to provide regular information during the growth cycle of crops and their sequence in time and space (Gillot 1980).

The remote sensing of vegetation and crops is complex because the reflected radiation from a crop canopy can be affected by several different factors. These can be summarised as follows:

i. The amount of radiation reflected is dependent upon the relative geometric positions of the incident radiation, the view angle of the sensor and the orientation of the crop as well the soil background.

ii. Both the growth stage and the water content of the crops affect the level of reflected radiation in particular wavelength regions.

iii. Cultural practices such as the application of fertilizer can vary from one crop to another and this causes differences in the reflectance properties of such crops.

iv. The intensity of solar radiation depends upon zenith angle and the physical composition of the atmosphere.

v. The row direction and spacing of a crop affects its reflectance properties (see also i).

vi. To monitor and forecast the production of a specific agricultural crop, particularly from satellite platforms, a mosaic of many scenes may be required. Cloudy weather, particularly in temperate regions, such as the U.K, may complicate this process.

Despite these problems, remote sensing remains a most important tool for agricultural data collection. The development of spaceborne platforms such as the Landsat series of satellites has encouraged the use of remotely sensed imagery in agriculture. Since the launch of Landsat-1 in 1972, satellite data have been used very successfully for acreage estimation and yield assessment. Production of a particular crop for a given geographic area, could be predicted by the combined use of acreage and yield data. Many projects which have used satellite data from different times in the growing season to monitor crop growth and predict levels of production (NASA 1978; LACIE 1978a; Dragg et al 1983; Amis *et al* 1981; MacDonald and Hall 1978; Mergerson et al 1982; Winings *et al* 1983). These programmes have established the methods for estimating area, yield and production of wheat in the USA and other major wheat-producing regions of the world (Myers 1983). Other programmes have been conducted for crops such as winter wheat, corn, soybeans (Mergerson 1981 ; Mergerson *et al* 1982 ; Hanuschak *et al* 1979 ; Amis *et al* 1981 ; Winings *et al* 1983 ; Erickson *et al* 1982 and Redondo *et al* 1984), potatoes (Ryerson *et al* 1980 ; Ryerson *et al* 1981 and Ryerson *et al* 1983) and sugar cane (Koffler *et al* 1980 ; Cappelletti *et al* 1982).

Redondo *et al* (1984) conducted a crop evaluation study for part of Argentina. The objective of their study was to establish a method for the estimation of wheat (the main Argentinean crop) in the northern part of the province of Buenos Aires using Landsat data. The crop identification accuracy that was obtained by the study was considered high enough to be implemented as a crop estimation system (Redondo *et al* 1984). Redondo (1982) also used Landsat MSS data for crop recognition and area estimation of wheat in Partido of Tres Arroyos in Argentina. The objective here was to establish the use of Landsat data for identifying cereal crops and estimating their areas for a typical wheat production area in Argentina during two consecutive years, 1980/81 and 1981/82 . Redondo concluded that cereal identification and area estimation was possible by the combined use of Landsat MSS data and ground truth information such as that collected by interviewing farmers.

After petroleum, wheat is largest commodity to be imported into Brazil. Therefore, it is important for Brazil to evaluate its wheat production in order to provide better information for trading. A procedure for estimating wheat area which uses sampling techniques based on aerial photography and digital Landsat data was developed by Moreira *et al* (1986). This study showed that the area estimates from Landsat MSS data and from aerial photographs were highly correlated but that wheat area estimated from a combination use of the two was more precise and accurate than that obtained from the aerial photographs alone (Moreira *et al* 1986).

Sugar cane acreage in Sao Paulo State in Brazil has been estimated using Landsat data (Cappelletti *et al* 1982). Cappelletti and co-writers developed a two phase estimation method and the optimal sampling area dimensions of the sugar cane cultivated area. INPE (Brazilian Institute for Space Research) designed a programme which developed a reliable, accurate and timely forecasting system for several crops based on satellite data. Investment in such programmes represented a high proportion of the funds allocated to the Brazilian agriculture sector as a whole (Parada *et al* 1982). Such programmes demonstrate the importance of remote sensing technology to agricultural information gathering.

The Food and Agriculture Organization (FAO) of the United Nations, has applied Landsat remote sensing technology for flood monitoring in some parts of the developing countries. Projects covered the catastrophic Indus floods in Pakistan in 1973 (Ruggles and Howard 1974) and the multi-temporal Landsat interpretation of the flood region of the Sudan Basin in southern Sudan (De Pauns and Spiers

1977). These projects have shown how successful the application of remote sensing technology for developing countries can be.

Abdel Hady *et al* (1983) have used Landsat data for the estimation of irrigated agricultural areas in the Delta and Nile Valleys in Egypt. The study estimated the irrigated agricultural lands in Egypt during the winter season of 1982 (Abdel Hady *et al* 1983) and showed that Landsat MSS data can be used to produce an inventory of irrigated lands in Egypt. The availability of accurate and reliable information on the agricultural lands can assist with the land use planning.

In 1978 the Commonwealth Scientific and Industrial Research Organisation (CSIRO) began a pilot project to investigate the role that Landsat MSS data could play in the crop identification process for the wheatbelt in Western Australia. In 1981 a collaborative project was established between the remote sensing group in the division of Land Resources Management in CSIRO, the Perth group of the Division of Mathematics and Statistics in CSIRO, and Cooperative Bulk Handling (CBH are responsible for the collection, storage, and transport of the wheat harvest in Western Australia). The project was created to evaluate the potential of Landsat data to estimate crop cultivated area, to discriminate between these crops, and ultimately to estimate yield in the wheatbelt of Western Australia (Campbell *et al* 1982). This project is a good example of a study designed to establish the capability of Landsat MSS data for providing accurate and reliable data on the acreage and yield of the crops in early stages prior to harvest. This valuable information can provide a powerful tool for planners concerning storage, transport, and marketing of agricultural crops.

Landsat MSS data have been shown to be more effective than the methods conventionally used for the monitoring of the rice paddies in the Philippines (Roque *et al* 1982) because of its cost, accuracy and reliability.

There have been many agricultural remote sensing studies in Pakistan. Most of these were related to the identification, demarcation, and area estimation of Pakistan's major crops such as wheat, rice, cotton (Alizai and Mirza 1986). Alizai and Mirza have reported that research studies into the use of Landsat data yielded accurate results but that accuracy varied from one crop to another . For example, areas given over to rice production were more accurately predicted than for wheat and cotton crops.

Remote sensing is a very powerful tool for gathering information on agricultural production because of its low cost per unit area, rapidity of sampling and ability to produce multi-temporal coverage easily. There are many factors that contribute to the fluctuation of agricultural production. Of these, the most important are disease and insects which damage crops and so reduce their yield. Since it offers an opportunity to survey large areas rapidly and economically, remote sensing affords great promise for the detection of diseases and insects.

Parton *et al.*(1982) conducted a study on the use of airborne Landsat Thematic Mapper Simulation data and aerial photography data in detecting cotton root rot (*Phymatotrichum omnivorum)* disease in Arizona. Parton *et al* concluded that, while the extent of infestation can be detected with aerial photography, the cost of periodic coverage makes this uneconomical. They further concluded that data from

Thematic Mapper Simulation was at a sufficient spatial and spectral resolution for the detection, tabulation and mapping of *Phymatotrichum* (root rot). The technical improvement of the Landsat series satellites resulting from the Thematic Mapper sensor and the detailed spatial resolution of French satellite SPOT has improved the availability of data on plant disease and insects.

An important parameter used to estimate the yield of a crop is Leaf Area Index (LAI) which is the area of green leaves per unit area of ground. Therefore, it is necessary to understand the methods for estimating LAI and the relationship between this parameter and the spectral reflectance of a crop canopy. The conventional methods of estimating LAI are time and labour consuming.LAI can be estimated by correlating the spectral reflectance of the crop canopy with its measured leaf area . LAI measurement depends on the spectral band used. For example LAI has a negative relation with red reflectance and a positive relation with near-infrared reflectance. To express this difference between red and infrared reflectance, a ratio of red to near infrared reflectance is used (Curran 1983a). The main limitation to the use of this ratio to estimate LAI is a need for cloudless sky condition for measurement of canopy reflectance (Asrar *et al* 1985).

Accurate and timely information on LAI has application in agriculture for both yield estimation and stress evaluation. It is also useful for the study of primary production and environmental change and many studies have been conducted on the development of new techniques for LAI measurements (Marschall 1968 ; Francis *et al* 1969 ; Colwell 1974 ; Pearce *et al* 1975 ; Hatfield *et al* 1976 ; Curran 1983a ; Asrar *et* *al* 1985 ; Best and Harlan 1985 ; Gardner and Blad 1986).

The influence of different cultural practices and environmental factors on LAI have been studied by Asrar *et al* (1985). They concluded that date of planting and time of irrigation in relation to the stage of plant growth had a significant effect on the development of leaves in spring wheat.

1.2. PREVIOUS MAJOR AGRICULTURAL REMOTE SENSING PROGRAMMES

The development of spaceborne platforms such as Landsat has increased the application of satellite remote sensing technology in agriculture. During the past two decades considerable evidence has accumulated to show that multispectral remote sensing from aerospace platforms can provide quantitative data which can identify major crop species and determine their areal extent (Craig *et al* 1978 ; LACIE 1978b ; Bauer *et al* 1979 ; Craig M. 1980 ; Honschak *et al* 1979 ; Hixon *et al* 1980 ; AgRISTARS 1981 ; Cappelletti *et al* 1982 ; Dragg *et al* 1983 ; Redondo *et al* 1983; Redondo *et al* 1984). The use of Landsat data as a tool in crop inventories is of particular significance.

The use of remote sensing technology in support of agricultural inventories and crop monitoring has resulted from research programmes such as the Large Area Crop Inventory Experiment (LACIE), the Corn Blight Watch Experiment and the Crop Identification Technology Assessment for Remote Sensing (CITARS) project (Dragg *et al* 1983 ; Myers 1983). These interrelated experiments were conducted to map and detect the corn blight effect in 1971, and to develop new techniques and procedures for classifying remote sensing data (Myers 1983). The most recent of these programmes is the Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS) which was designed to develop automated approaches for extracting global crop inventory information from data sets acquired by spaceborne sensors (AgRISTARS 1982 ; AgRISTARS 1983 ; Dragg *et al* 1983). Despite their global objective, these projects have been carried out in the USA. For a variety of reasons which will be discussed later, area estimation and crop monitoring using satellite data has not been widely applied in Europe. The AGRESTE project was the only European remote sensing programme for crop inventory and monitoring.

1.2.1. THE CORN BLIGHT WATCH EXPERIMENT

The Corn Blight Watch Experiment was initiated in 1971 by NASA, USDA, Purdue University, and the University of Mitchigan. The experiment was conducted in seven Corn Blight states, Illinois , Indiana, Missouri, Ohio, Iowa, Nebraska, and Minnesota. The main objectives of the programme were to detect the development and spread of corn blight during the growing season across the Corn Belt region, and to assess different levels of infection present in the Corn Blight (Myers 1983). The experiment provided a prototype remote sensing system by successfully integrating techniques of sampling, data acquisition, storage, retrieval, processing, analysis, and information dissemination. (Bauer *et al* 1977). The results obtained by the experiment have established the possibility of using remote sensing operationally to detect the corn leaf blight.

1.2.2. CITARS

CITARS (Crop Identification Technology Assessment for Remote Sensing) was conducted from April 1973 to April 1975. The CITARS experiment was designed to quantify the crop identification performance of several automatic data processing (classification) techniques which used Landsat MSS data. The main objectives of CITARS (Myers 1983) were to assess:-

i) the effects of Landsat data acquisition during the corn and soybean growing season on crop identification,

ii) the effects of different soils, weather, management practices, crop distributions, and field sizes on crop identification, and

iii) the benefits to be derived from using multi-temporal Landsat imagery.

The CITARS experiment showed that multi-temporal data improves the accuracy of both crop identification (classification) and yield estimation. CITARS was a valuable step toward the wide spread application of satellite remote sensing. It contributed significantly to the establishment of the LACIE experiment.

1.2.3. LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)

The roots for LACIE were established as early as 1960 by the Agricultural Board of the National Research Council in the United States to test the feasibility of using multispectral remote sensing data for crop monitoring. The success of several feasibility investigations conducted with Landsat-1 data coupled with the development in remote sensing data processing techniques, led to the design and introduction of LACIE (Large Area Crop Inventory Experiment) in 1973-74. The LACIE project was a logical step to establish the technical feasibility of a global agricultural monitoring system (LACIE 1978a ; LACIE 1978b ; Erb 1980).

LACIE was established as a cooperative project of the United States Department of Agriculture (USDA) ; National Aeronautics and Space Administration (NASA) ; and the National Oceanic and Atmospheric Administration (NOAA). The experiment established the techniques for estimating area, yield and production of wheat in the USA and other major wheat-producing regions of the world. LACIE used Landsat data from different times in the growing season to monitor agricultural crops.

The USA began to apply satellite remote sensing technology on an experimental basis to publicise accurate forecasts of its wheat production areas. LACIE was initiated to demonstrate this. However, it has provided accurate, timely information on foreign wheat production and that information was more accurate than the conventional data-collection methods that were available.

The LACIE objectives were included in a project plan, prepared in March 1975, and officially approved in August 1975. These objectives include the following (LACIE 1978a ; LACIE 1978b ; Erb 1980 ; Bauer *et al* 1979a):-

i) To demonstrate an economically important application of repetitive multispectral remote sensing from space.

ii) To test the capability of the Landsat, together with climatological, meteorological, and conventional data sources, to estimate the production of an important world crop - wheat.

iii) To validate the technology which could provide timely estimates of crop (wheat) production commencing in 1975.

iv) To provide, from an analysis of Landsat data acquired over a sample of the potential crop-producing areas in major wheat producing regions, estimates of the area planted to wheat. Also, to provide from an analysis of historical and meteorological data over the same regions, estimates of wheat yield and combine these area and yield factors to estimate production levels.

v) To provide data processing and delivery techniques so that selected samples can be made available to the LACIE scientists to begin their analysis no later than 14 days after the data are acquired.

vi) To provide a LACIE system design that will permit a minimum of redesign and conversion to implement an operational system within the USDA.

vii) To monitor and assess the status of a crop at different stages in its growth and to predict the yield using a ground data base.

LACIE also made an assessment of a crop at different stages during the growing season from planting through to harvest. It accounted for the effects of cultural and environmental variables on the spectral properties and spectral identification of wheat (Bauer *et al* 1979a). The main objective of the experiment was to provide estimates at harvest within the 90/90 criterion* for total wheat area production level estimates. An additional aim was to provide this information on a monthly basis. LACIE focused on improving methods of data processing in the analysis of multitemporal data.

The project extended over three experimental Phases. Phase I (1974-75) was focused on the estimation of wheat production in the US Great Plains. It also considered testing the feasibility of area and yield estimation systems. Therefore, Phase I has modified the technology for production estimation.

Phase II was extended over the 1975-76 crop year. It evaluated the tech-

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* *Meaning that the at harvest wheat production estimate for the region or country should be within 10 percent of the true production with a probability of at least 0.9.*

nology, which developed in Phase I, for monitoring wheat production in the US Great Plains, Canada, and indicator regions in the USSR (LACIE 1978a ; LACIE 1978b ; Erb 1980). Monthly estimates of area, yield, and production of wheat for these areas were generated by LACIE.

The new technology developed during Phase II was implemented in Phase III to evaluate and monitor wheat production in the US Great Plains and USSR. LACIE generated monthly reports of area, yield, and production level estimates of wheat for these regions. The experiment included exploratory studies for monitoring wheat production in five other major producing regions (India, China, Australia, Argentina, and Brazil).

The overall objectives of LACIE were to develop and test techniques utilising Landsat MSS data to identify, evaluate and estimate wheat area, yield and production over large geographic areas. The experiment produced impressive results. Those who evaluated the LACIE experiment reported that it had successfully (LACIE 1978a):-

i) produced accurate results in important areas such as US hard red winter wheat region,

ii) provided a basis for a comprehensive research, development, and test programme to extend the capability to other crops,

iii) stimulated related research and technology development,

iv) provided more efficient and accurate procedures for analysis.

LACIE has stimulated significant technological improvements. The major technical advances as reported by LACIE (1978a) were the development of computer-aided Landsat data processing procedures, and improved sampling efficiency through stratification based on Landsat data. Furthermore, the LACIE project improved the regression models for estimating wheat yields and statistical methods for accuracy assessment (LACIE 1978a).

1.2.4. AgRISTARS

The AgRISTARS (Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing) programme is a cooperative effort of the United States Department of Agriculture (USDA); the National Aeronautics and Space Administration (NASA); the National Oceanic and Atmospheric Administration (NOAA); the US Department of Commerce (USDC); the US Department of Interior (USDI); and the the Agency for International Development (AID). AgRISTARS is a long-term programme to investigate the use of remote sensing in agriculture.

The AgRISTARS programme was established in 1980, as an effort based on satisfying current and future requirements of the USDA for high priority agricultural and other renewable resources information. The USDA requires this information in order to address the national and international issues in food supply, demand and prices. The USDA information requirements include (AgRISTARS 1981 ; AgRISTARS 1982 ; AgRISTARS 1983):

i) Early warning of change affecting production and quality of commodities and renewable resources.

ii) Commodity production forecasts.

iii) Land use classification and measurement.

iv) Renewable resources inventory and assessment.

v) Land productivity estimates.

vi) Conservation practices assessment.

vii) Pollution detection and impact evaluations.

The AgRISTARS programme was developed on the basis of these information requirements. The experiment consists of eight projects in order to fulfil the need of USDA's information requirements. The eight projects include the following (AgRISTARS 1981 ; AgRISTARS 1982):-

- Early Warning and Crop Condition Assessment (EW/CCA).
- Inventory Technology Development (ITD), formerly known as the Foreign Commodity Production Forecasting (FCPF) project.
- Yield Model Development (YMD).
- Supporting Research (SR).
- Soil Moisture (SM).
- Domestic Crops and Land Cover (DCLC).
- Renewable Resources Inventory (RRI).
- Conservation and Pollution (CP).

Each project has its own specific aims. Nevertheless, they are closely interrelated and both information and technology are often shared.

The Statistical Reporting Services (SRS) has been responsible for the implementation of the DCLC project since 1972. In 1980, DCLC became an applications project. The overall technical objectives of DCLC as reported by AgRISTARS (1981) and AgRISTARS (1982), were :-

i) the evaluation of research techniques for area estimation and development for an operational procedure for crop acreage estimations; and

ii) the development of remote sensing techniques to satisfy the land cover information needs of the USDA.

Kansas and Iowa were chosen as the first two states in 1980 to be included in the project. The project has grown in size every year as described in the annual reports (AgRISTARS 1981 ; AgRISTARS 1982 ; Kleweno and Miller 1981 ; Mergerson *et al* 1982 ; Winings *et al* 1983 ; Cook *et al* 1984). In 1981, the states of Missouri and Oklahoma were included in the programme. The states of Colorado and Illinois were added in 1982. The main objective for DCLC was to obtain more accurate crop area estimates for the winter wheat, corn and soybeans.

The SRS provided up to date estimates with reduced sampling errors by using ground data coupled with Landsat data (Mergerson et al 1982). The main objective was to measure the overall relative efficiency (RE) at the substate level for each crop to be estimated. Mergerson *et al* (1982) have defined RE as a measure of the degree of improved precision obtained from using Landsat data in addition to the ground data. Cook *et al* (1984) have defined it as the ratio of the JES (June Enumerative Survey) state level direct expansion variance to that of the Landsat regression variance (Cook *et al* 1984).

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.

1.2.5. AGRESTE PROJECT

Despite their global objectives, the projects mentioned so far have been concentrated on areas and techniques in the USA. The AGRESTE (Agricultural resources investigations in Northern Italy and Southern France) was the only agricultural remote sensing project to be established in Europe between 1973 and 1977. It was sponsored by the Commission of the European Communities to investigate the potential of remote sensing applications to agriculture and forestry under the European conditions. The main areas chosen to represent these conditions were Northern Italy and Southern France. The project was carried out from 1973-77 as a cooperative project between the Joint Research Centre, Ispra and National French and Italian Institutes.

The main objectives of AGRESTE were the identification and inventory of specific agricultural crops and forestry resources and the estimation of the yield and biomass of crops using remote sensing techniques. The crops studied by the AGRESTE included irrigated rice, poplar, and beech forests. Northern Italy was chosen as one of the study areas, because most of the Italian rice fields (91.4% in 1975) are concentrated in this part of the country (Dejaco and Megien 1980).

The project used Landsat MSS data obtained from the satellites Landsat-

1 and Landsat-2 as well as colour infrared photography, ground truth, and airborne MSS data. These data sets allowed the studies in France and Italy to be directly comparable (Berg *et al* 1978).

The AGRESTE programme has shown that, the discrimination of rice varieties is possible using Landsat MSS data. On the other hand, the yield prediction has been achieved with satisfactory results on the basis of reflectance data collected at the earing-flowering stages (Berg 1980). Area estimation for rice using the Landsat MSS data was more complicated when the individual fields can be, at any given time, at different stages of development. The project has successfully separated the beech forests from other categories.

The main limitation which appeared from the project was the inadequacy of Landsat MSS spectral bands for precise discrimination of the vegetation canopies. As will be discussed in chapter 3, the improved spectral coverage of the Landsat-TM sensor has, in part, addressed this problem.

1.2.6. DUTA PROJECT

In 1980, a multi-year project for the agricultural application of atellite remote sensing was was established in Italy called DUTA (Determinazione e Utilizzo di Telerilevamento in Agricoltura) . The programme was the first systematic attempt performed in Italy with the aim to integrate satellite data in operational procedures for estimating the production of agricultural crops of great economic importance and obtaining useful information for managing water resources (Angelis and Gizzi 1984). The first phase of the DUTA programme (DUTA-1) was aimed at testing the feasibility of using the satellite data in Italy for crop acreage estimates, crop production forecast, water resource management and flood damage assessment.

DUTA used a multi-level approach based on the combined use of ground and satellite data. The results obtained have shown that the acreage estimates for wheat and corn can be obtained using satellite data, thus achieving increased accuracy for a given amount of ground collected data, or, conversely, a reduction in the need for ground data for a specific level of accuracy.

During the DUTA project, statistical techniques have been developed in order to evaluate the effects of different stratification schemes (including spectral classification of satellite data) in terms of increased estimation of accuracy (Anglis and Gizzi 1984). Furthermore, it developed a cost/benefit analysis of stratification procedures and an evaluation of the best set of non-satellite information to be used in conjunction with Landsat data.

In 1985 DUTA project was renamed as AGRIT1 (Agricultura). Since then the programme has been implemented each year and the latest project AGRIT5 was started in 1989 (Luzi *et al* 1989).

1.2.7. SUMMARY

Advances in satellite agricultural remote sensing have resulted from the above research programmes. These interrelated experiments have tested the feasibility of using Landsat data for crop production information and have showed that crop identification and area estimation can made using Landsat data. They have achieved satisfactory results for area and yield estimation prior to harvest. Furthermore, they produced more efficient and accurate procedures for satellite remote sensing data analysis. All of the experiments have developed automated approaches for extracting global crop inventory information from data sets acquired by spaceborne sensors.

These studies demonstrate that the use of Landsat data has considerable advantages compared with other remote sensing methods such as aerial photography. However, the application of Landsat MSS data to agriculture has limitations including that of the spatial resolution of the MSS sensor and its limited spectral coverage. Table (1.1) illustrates the main agricultural remote sensing programmes showing their location, date, data used and organisations involved.

Table 1.1
The Main Agricultural Remote Sensing Programmes

Project	Date	Data used	Location	Funded
Corn Blight Watch	1971	University of Michigan 12-channel multispectral scanner mounted on a C-47 aircraft	U.S.A	NASA, USDA, Purdue University and Michigan University
CITARS	1973	Landsat MSS	U.S.A	EOD of NASA. ERIM. LARS and ASCS of USDA
LACIE	1973	Landsat MSS	Major wheat producing regions in USA, Canada USSR, Brazil, Argentina China, India, Australia	USDA, NASA NOAA
AgRISTARS	1980	Landsat MSS	U.S.A	NASA, USDA, NOAA USDC, USDI and AID
AGRESTE	1973	Landsat MSS	Northern Italy and Southern France	Joint Research Cente, Ispra and National French and Italian Institutes.
DUTA1	1982	Landsat MSS	Italy	Italian Ministry of Agriculture and Forestry (MAF).
DUTA2	1984	Landsat MSS and TM	Italy	MAF
AGRIT1	1985	Landsat TM	Italy	MAF
AGRIT2	1986	Landsat TM	Italy	MAF
AGRIT3	1987	Landsat TM	Italy	MAF
AGRIT4	1988	Landsat TM	Italy	MAF
AGRIT5	1989	Landsat TM	Italy	MAF

1.3. STATEMENT OF THE PROBLEM

Crop type area estimation is of interest to both governmental and private-sector organisations. Government departments require it for administrative purposes, possibly to regulate quantities or prices or as a basis for external trade policies. Farmers themselves may use the harvest data calculated for their county or country as the basis for seasonal purchases in order to obtain particularly favourable prices. Marketing policies taken by the private sectors depend by large extent on such information.

In England land-use statistics including crop type acreage are collected by means of a postal questionnaire sent by the Ministry of Agriculture, Fisheries and Food (MAFF) to every known occupier of an agricultural holding producing significant output. The main survey is conducted on 4th of June or the preceding Friday when the date falls on a Saturday or Sunday.

The present position in respect of land-use data in general in United Kingdom is clearly unsatisfactory because the inability or unwillingness of the farmers to provide accurate information (Coppock 1979). Unreliability and inaccuracy of crop type area estimation may occur for the following reasons.

i. Farmers are asked to provide information correct to the nearest quarter of acre rather than precise area. Many of these figures can only be estimates.

ii. Occupiers are asked to give the acreage of fields shown on the Ordnance Survey maps, which they may not have access to. Even if they have, the area under the crop may considerably less than the area recorded on these maps, especially where fields have large hedges or boundaries.

iii. Farmers may call some of their fields by approximate area (e.g, the 8-acre field).

iv. The acreage under each crop or prepared for that crop on the survey day is recorded rather than the maximum acreage under that crop during the crop year.

v. New hedges or boundaries may have been set up or removed because two or more fields have been subdivided or joined together.

Therefore, improvement and development of new techniques for crop type area estimation are needed in order to improve the accuracy, timeliness and consistency of the agricultural crop information base in the UK.

Remote sensing has proved to be a useful tool for monitoring of certain of the major agricultural areas of the world with large field sizes. But its application in Europe has been limited to specific regions because of small farm units which characterise most of the agricultural areas through the region (see section 2.7). County Durham is a typical example of an agricultural region with small field sizes.

During the past two decades considerable evidence has accumulated to show that multispectral remote sensing from aerospace platforms can provide quantitative data which can be used to identify major crop species and determine their areal extent. Remote sensing techniques, may prove to be a more accurate, precise, rapid and cost effective method of acquiring crop acreage estimates than conventional surveys carried out on the ground. Moreover, it is even more valuable when remote sensing is not required to furnish the complete answer, but rather it used in conjunction with other sources of information. The purpose of this study is to develop a method using satellite and field data for estimating the areal extent of the important agricultural crops in County Durham. It builds upon the above research programmes by applying a double sampling approach which can be evaluated quantitatively.

Double sampling is a two-phase sampling technique which utilises remote sensing data as the first phase. In this study the double sampling method is used to produce an acreage estimate which is based upon a combination of landsat TM and field data. The rationale for this combination is that Landsat TM data can produce an acreage estimate over large geographic areas at a small cost per unit area. Moreover, Landsat data can produce a complete census for the whole area of interest which in turn results in no sampling error (imprecision). Despite all of these advantages, Landsat data can have statistical measurement error (bias). As a result of the bias produced by Landsat data, double sampling can be implemented on the basis of combining Landsat TM data and field measurements to produce more precise and unbiased estimates over large areas. The principal reason for using the field survey is that, if implemented with care, it can reduce bias. The double sampling technique is a combination of two measurement techniques which when used in conjunction help to overcome the problems associated with each survey and reducing both the measurement and the sampling errors.

1.4. THE OBJECTIVES OF THE RESEARCH

The overall objective of the investigation is to develop and test techniques for using Landsat TM data to identify and determine the areal extent and distribution of crops over large geographic areas in the U.K., specifically for crop identification and area estimation for County Durham in North East England. The objectives are:-

1. - to test the role of satellite data for discrimination of different crops over the whole area of County Durham.

2. - to test the validity of using a satellite data set for deriving hectarage estimates over large areas applying the crop identification data obtained from the classification of Landsat TM data,

3. - to evaluate and compare the accuracy of Landsat-TM data for making improved hectarage estimates compared with conventional ground data collection techniques,

4. - to assess the accuracy of a hybrid method of area estimation combining satellite and field data, and

5. - to assess the efficiency of making hectarage estimates using the hybrid method rather than conventional sampling techniques.

1.5. THESIS STRUCTURE

A brief review of satellite remote sensing programmes in agriculture has been given and the research objectives were illustrated. Chapter two gives details of the various physical aspects of the study area and explains the reasons for the choice of Durham County as the research study area. Details of the various data sources selected for this study are given in chapter three. This includes a brief discussion of Landsat data and the reasons for its use in this study.

Chapter four describes the methodology for estimating crop type area using field data by applying a stratified random sampling approach. It discusses in detail the method of choosing and allocating sample units on both air photos and on the satellite imagery. The statistical methods for crop type area estimation using a stratified random sampling scheme is discussed in this chapter.

The methodology for estimating crop type area in County Durham using Landsat-TM data is illustrated in chapter five. The chosen method of Landsat classification is also discussed in this chapter. This includes an assessment of the classification process and assessment of its accuracy. The reasons for any misclassification of the data is also analysed in chapter 5.

The overall objective of this study is to determine a procedure which may produce more accurate and timely estimates of the area of agricultural crops in County Durham. To produce such estimates, chapter six outlines the general methodology applied. The efficiency of using the double sampling technique over the conventional methods is also assessed.

Finally, chapter seven summarises the results of this research and makes recommendations and implications for future research into the use of satellite imagery for crop type area estimation and land cover studies.

CHAPTER TWO

THE STUDY AREA

2.1. Introduction.

2.2. Location and Topography.

2.3. Geology.

2.4. Soils.

2.5. Climate.

2.6. Agriculture and Vegetation.

2.7. Summary.

2.1. INTRODUCTION

This chapter describes the study area and explains the reasons for choosing County Durham as the research site. The first section describes the geographic location and the topography of the area. The subsequent sections discuss geology, soil types, climate, vegetation and the agricultural pattern of the area. Section 2.7 summarises the main reasons for the choice of study area.

2.2. LOCATION AND TOPOGRAPHY

County Durham is located in the north-east of England. Figure 2.1 shows the major administrative districts of the county. It extends from the North Sea in the east to the County of Cumbria in the west. In the south and south west it borders North Yorkshire and Cleveland to the south east. The County abuts Tyne and Wear in the north east and Northumberland in the north west.

The topography of the area has been strongly influenced by the geological formation of the area. The topography of County Durham ranges from moorlands to the west at over 2400ft above sea level, to marshes standing at sea level. The majority of the county's area is about 500ft above sea level (see figure 2.2). Topographical regions within the study area is are defined by Beaumont (1967) as the following :

1. the Pennine Uplands,
2. the Wear Lowlands,
3. the East Durham Plateau, and
4. the Tees Lowlands.

The largest of these is the Pennine Uplands which covers the whole western part of the county. It is characterized by the moorlands underlain by carboniferous strata whose valley sides have a stepped form reflecting the underlying geology of the Yoredale Series. The Pennine Upland region contains Burnhope Seat which represent the highest point in the county at 2452ft above sea level.

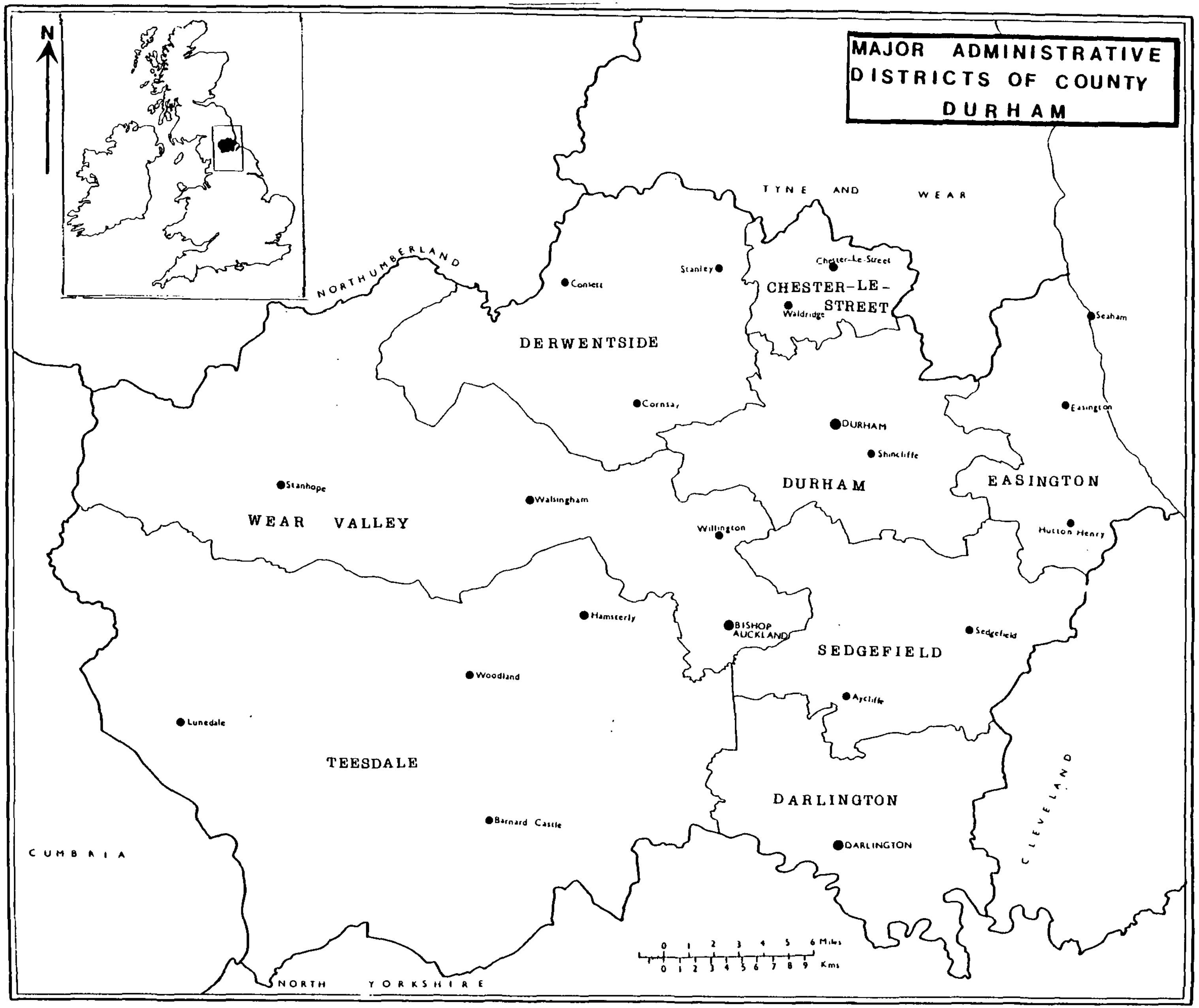
The second main topographic region in the area is the Wear Lowland which may be divided into three areas (Brown 1978) they are:

- Upper Wear Lowlands,
- Middle Wear Lowlands, and
- Lower Wear Lowlands.

The Pennine Magnesian Limestone Escarpment rises from beneath thick superficial deposits to mark the third main topographic region, the East Durham Plateau. The height of the Escarpment ranges from 500 to 600ft and reaches its highest elevation of 715ft to the south west. Its height decreases as one moves northwards (Beaumont 1970).

South of the Magnesian Limestone Plateau, the land drops in altitude into the thick drift covered Tees Lowland (Brown 1978). This region represents the fourth main topographic area in the county. In this region the land is below 400ft O.D and much of it is below 100ft (Beaumont 1970).

Figure 2.1


MAJOR ADMINISTRATIVE DISTRICTS OF COUNTY DURHAM
N
TYNE AND WEAR
NORTHUMBERLAND
CUMBRIA
NORTH YORKSHIRE
CLEVELAND
DERWENTSIDE
CHESTER-LE-STREET
DURHAM
EASINGTON
WEAR VALLEY
SEDGEFIELD
TEESDALE
DARLINGTON
Consett
Stanley
Chester-Le-Street
Waldridge
Seaham
Cornsay
DURHAM
Shincliffe
Easington
Stanhope
Walsingham
Willington
Hutton Henry
Hamsterly
BISHOP AUCKLAND
Sedgefield
Woodland
Lunedale
Aycliffe
Barnard Castle
DARLINGTON
0 1 2 3 4 5 6 Miles
0 1 2 3 4 5 6 7 8 9 Kms

Northern England *(Geol. Surv.)* PLATE II

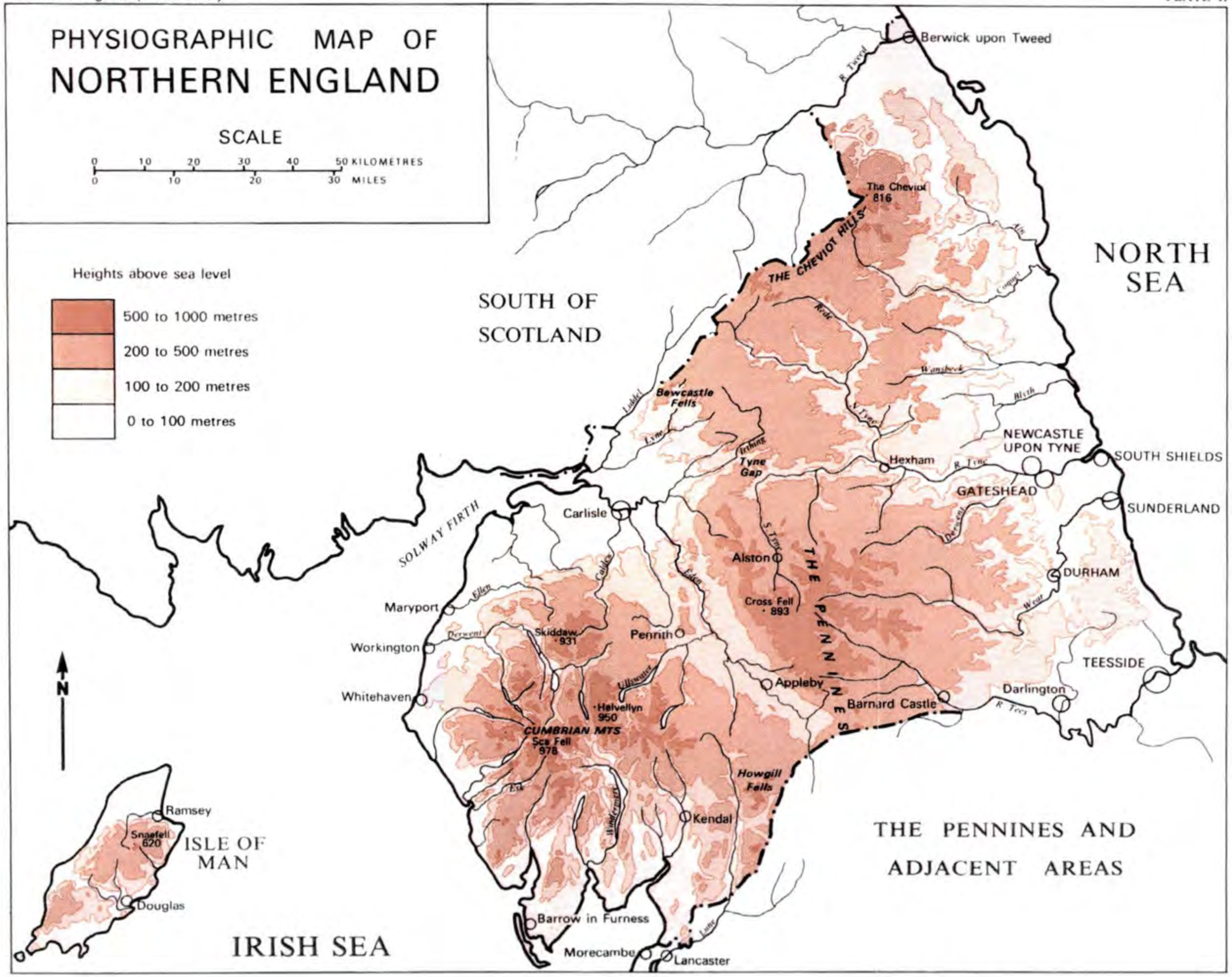


FIGURE 2.2

Source: British Geological Survey, Northern England (1971)

2.3. GEOLOGY

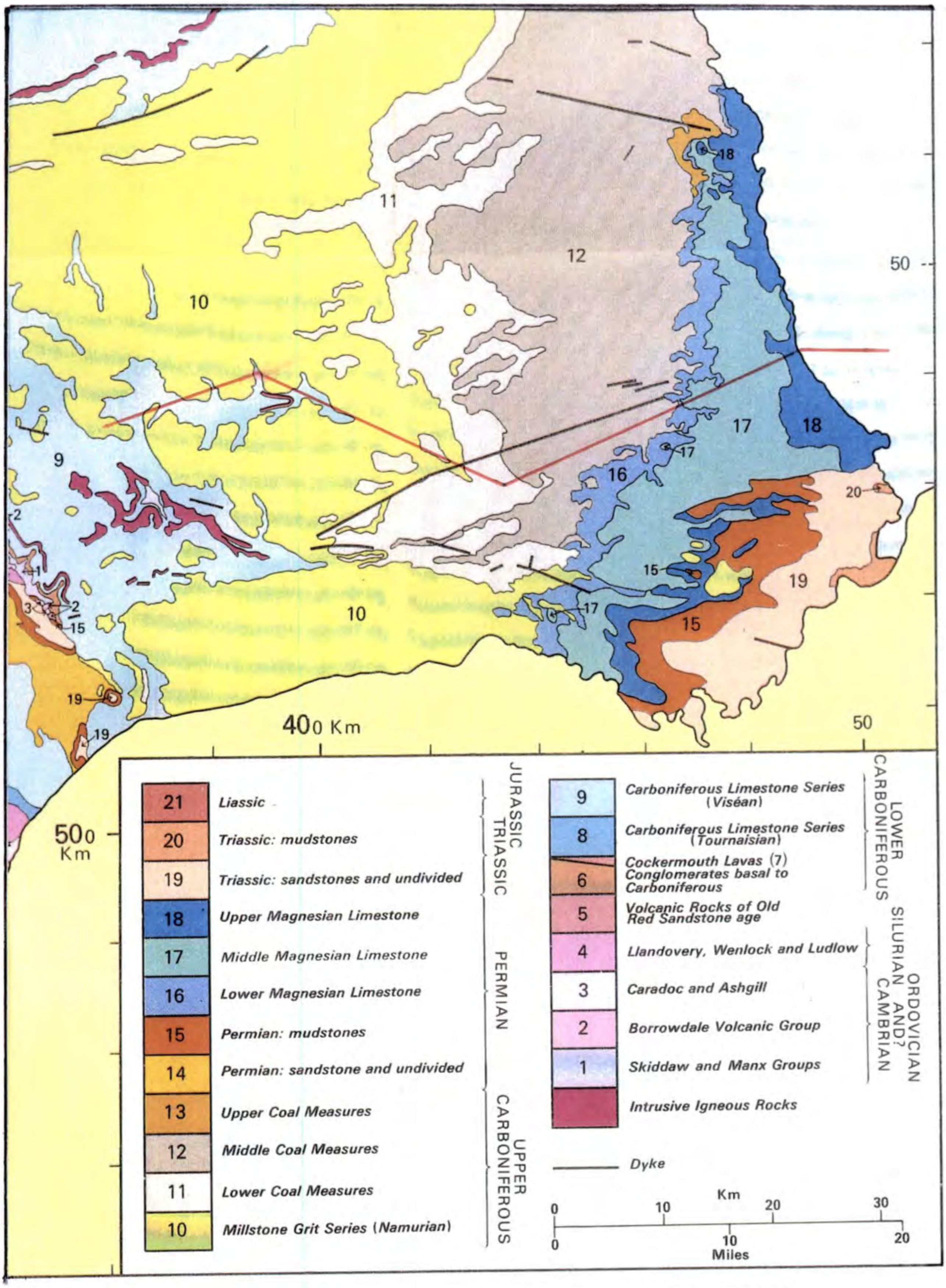
The solid geology of County Durham is illustrated in figure 2.3 The rocks which underlie the region are mainly of Upper Carboniferous and Permian age. The geological structure is affected by three major periods of earth movement which have contributed to the tectonic evolution of northern England (Beaumont 1970). These periods have brought the rocks gradually to the positions which they now occupy.

The geological control for the area is exerted by variations in the hardness of the rocks and their resistance to erosion. Thus, the soft shales and relatively poorly cemented sandstones of the Permian and Trias generally outcrop in valleys; and unrestricted shales of the coalfields form relatively low ground relieved by a subdued escarpment formed by the thicker sandstones (Taylor *et al* 1971).

Coal measures shales and mudstones are mainly dark grey in colour and pass upwards into paler siltstones (Johnson 1970). The thickness of the coal measures in Durham is of 2000ft and according to Beaumont (1967) divided into three divisions, the Lower, Middle and Upper Coal Measures. The workable coal is restricted to the Lower and Middle Coal Measures in County Durham. The Durham coal exhibits a wide range of rank, quality and physical characterestics ranging from the soft coking coals with less than 30 percent volatile matter to hard dull coals with over 36 percent volatile (Johnson 1970). There a large reserves of coal in Durham which coal mining a major industry in the County.

The soil of the area has been significantly influenced by the Permian strata. These strata includes mainly the Lower Magnesian Limestone, Marl Slate and Basal

Fig. 2.3
Sketch Map of the Solid Geology of County Durham

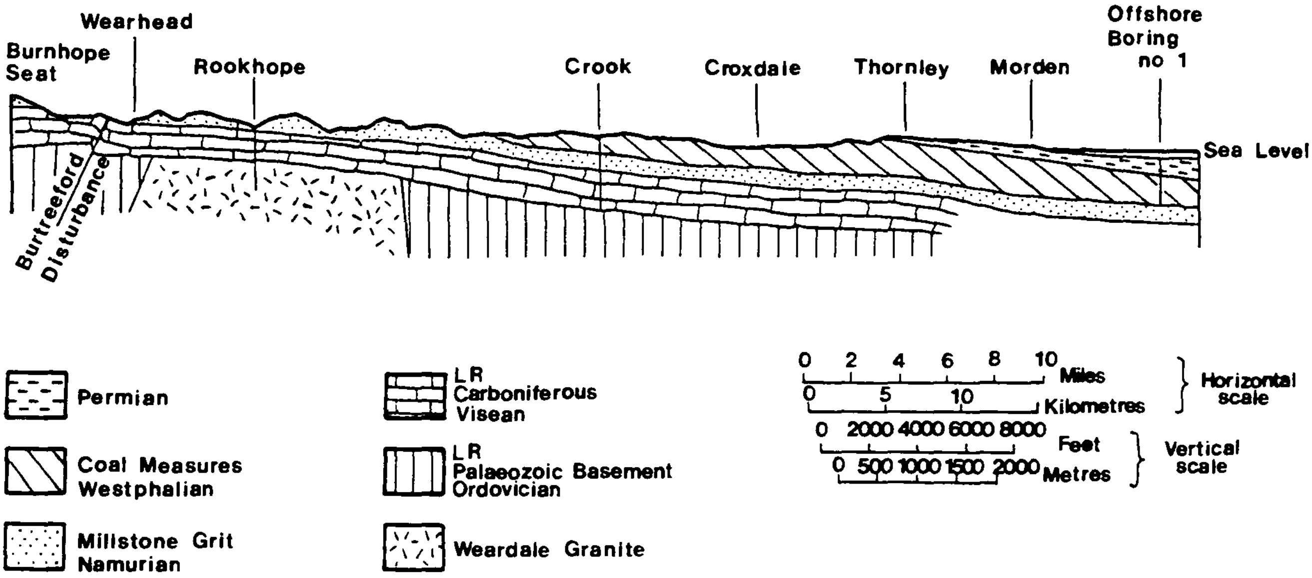


Source : British Geological Survey, Northern England (1971)

Fig. 2.4 GEOLOGICAL SECTION

Horizontal section across County Durham,
showing the disposition of the major divisions of strata.

The line of the section is given in Fig. 2.3.



Source :- Johnson (1970)

Sands (Johnson 1970). In the coastal area of the County and the Tees Lowlands, as in the Wear Lowlands, a composite sequence of Glacial deposits is found, while on the Permian Plateau only a single till sheet with associated gravel is present (Beaumont 1967 ; Brown 1978). Figure 2.4 illustrates a horizontal section across County Durham showing the deposition of the major divisions of strata.

2.4. SOILS

The soil of County Durham is influenced by six main factors, climate, parent material, relief, biotic factors, time, and man (Stevens and Atkinson 1970). The climatic includes precipitation and temperature which control the soil formation process. The influence of relief may clearly seen when the rainfall isohyets are considered, as they follow the contour lines quite closely. The Upland Pennines, over 2000ft have always received high annual precipitation totals during Post-Glacial times. This has resulted in the formation of peat and peaty soils (Atkinson 1968).

The most important factor affecting soil quality within the county, apart from elevation and climate is the quarrying and open-cast mining. This in turn imposes restrictions on land utilisation for agriculture. Considerable areas have been affected by open-cast mining and even when the land has been restored for agricultural use the soil formation and capabilities have been interrupted (Stevens and Atkinson 1970).

The effect of man on the soil in the region is substantial. This is obvious in the Lowlands where the majority of the land has been cultivated. As is clear from figure 2.8 the east of the County and some of the central areas are heavily cultivated and man's influence as a soil forming factor has been strong (Stevens and Atkinson 1970).

In the moorland areas, the major factor which controls the soil distribution is the altitude. The parent material texture also strong influence on the soil type in that area. On the lower slopes and valley bottoms an extensive deposit of glacial till of clay loam texture occurs, while the texture varies from clay loam to sandy clay loams on the upper slopes. The high ground of the Pennines is extensively covered by the blanket peat. The peat cover extends over a wide range of land surfaces and surface deposits ranging from coarse sandstones to clay loam slope deposits (Bower 1961 ; Atkinson 1968).

On the higher hills along the western part and in some other parts both inland and along the coast, the Magnesian Limestone is free of drift cover and sedimentery limestone soils have developed. These soils are mainly thin, dark brown and loamy. The general map of soil type distribution through the County is illustrated in figure 2.5. As we can see from the figure, soil type can be a very important basis for stratification of the study area (see section 4.5).

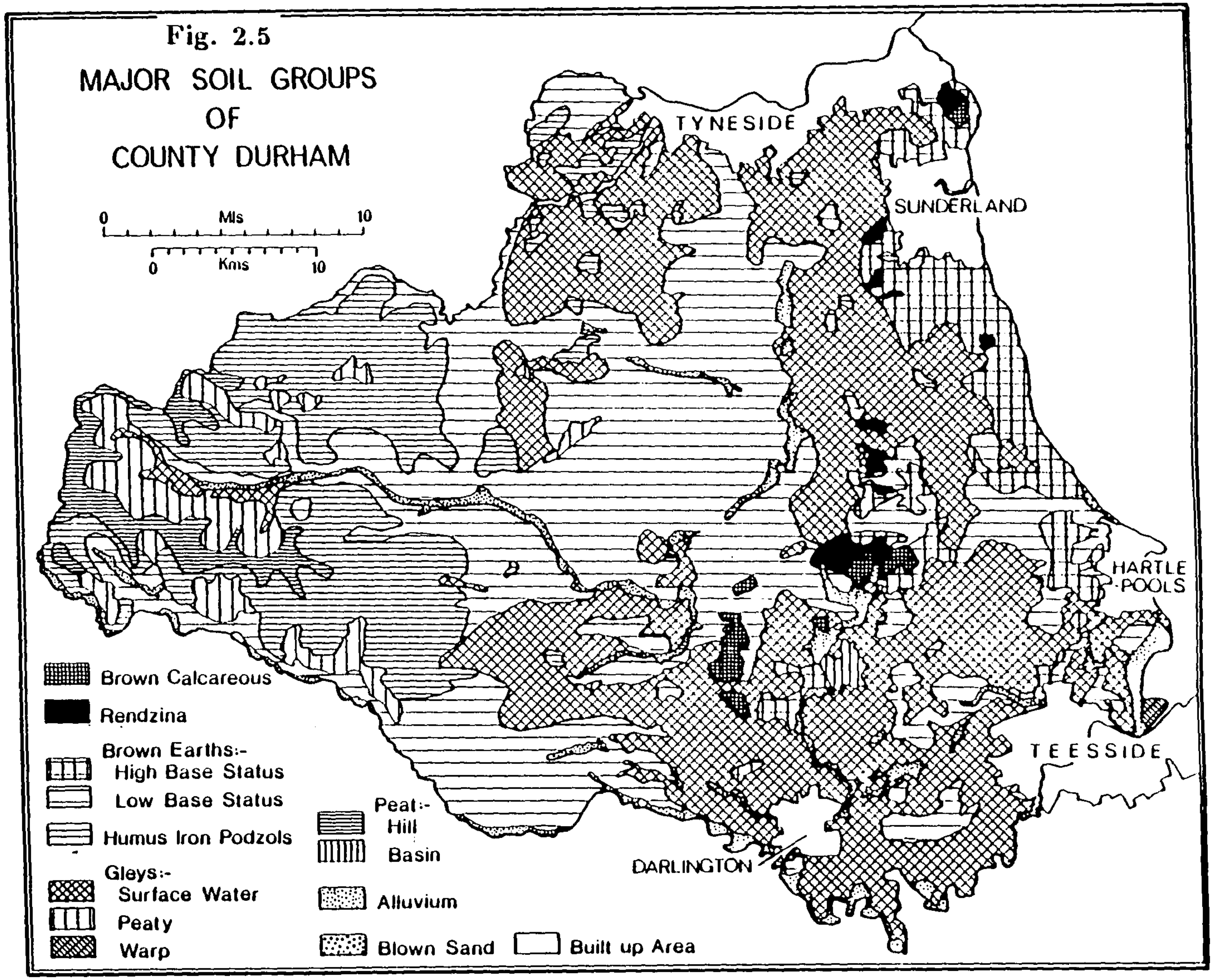


Fig. 2.5
MAJOR SOIL GROUPS OF COUNTY DURHAM

Source: Stevens and Atkinson (1970)

2.5. CLIMATE

The climate of County Durham is characterised by its cold winter, late spring, short summer and east winds. Weather patterns are clearly influenced by relief and topographic location. This is illustrated in figure 2.6.

Rainfall is high in the upper parts of Weardale and Teesdale with average of 1650mm. With decreasing altitude, precipitation declines steadily towards the coast until mean totals of approximately 650mm are found over large areas of the Lower Tees valley below Darlington (Smith 1970) and in some areas in the north east of the County close to the coast (see figure 2.6). Table 2.1 shows the average annual and monthly rainfall (mm) and maximum fall in 24 hours over Durham and Hartlepool for the period 1951-80.

Table 2.1 Average Annual and Monthly Rainfall (mm) and Maximum Fall in 24 Hours Over the Period 1951-80

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Durham													
Average	58	47	45	39	54	51	54	72	54	52	62	57	645
Maximum Fall in 24 Hours	29.7	23.9	50.6	32.2	35.2	33.4	43.9	50.3	87.8	39.1	40.2	34.3	
Hartlepool													
Average	52	41	41	35	47	51	53	63	48	50	66	55	602
Maximum Fall in 24 Hours	29.6	22.1	47.3	21.1	36.3	26.4	41.7	51.8	60.4	47.0	37.1	33.8	

Source : Meteorological Office 1984.

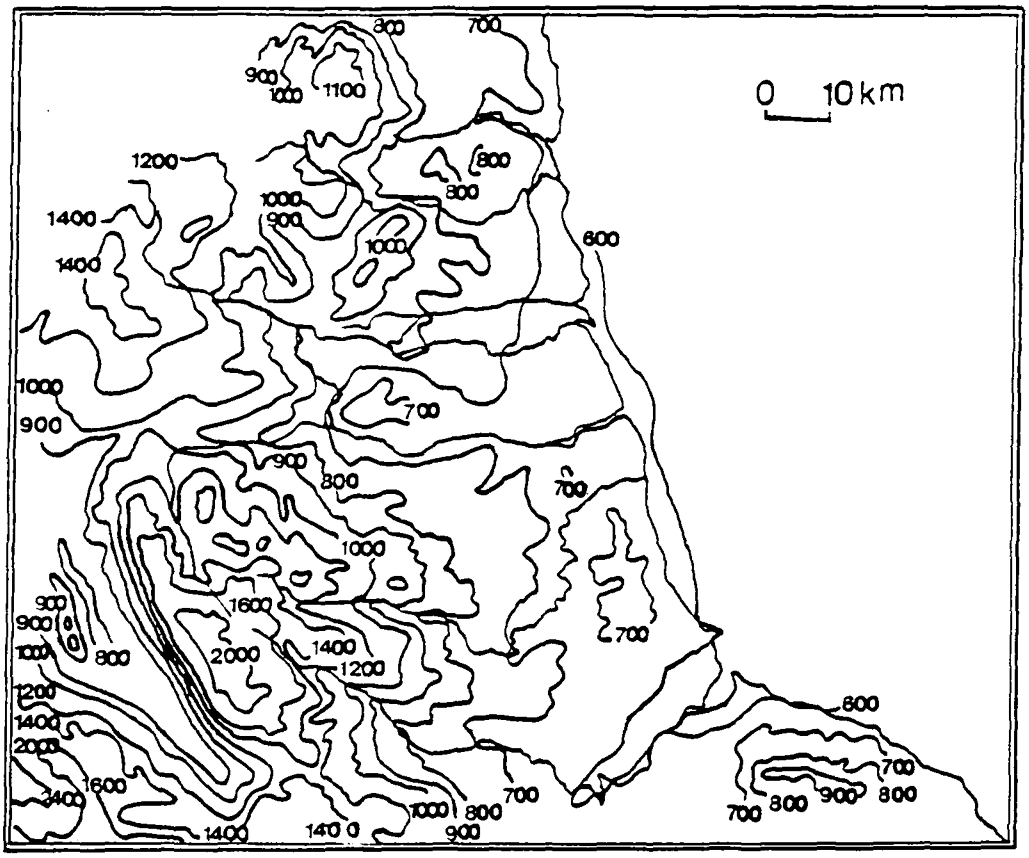
Because the cumulative effect of the northerly altitude and the coolness of the North Sea, relatively low mean annual temperatures are found in the County (Brown 1978). Temperature also relates to relief, in the uplands the greatest differences in maximum temperature as compared with lowlands values appear to occur in late spring (Smith 1970).

When a warm humid air mass passes over the cool North Sea particularly in spring, there is a tendency for fog and low cloud on the east coast known as "haa" in Scotland and "Sea-fret" further south. Sometimes reaching as far as inland Durham and in some years may last for several days (Manley 1952).

This area is characterised by being more cloudy in winter than in summer and more cloudy by day than by night. Table 2.2 gives the percentage frequency by month and year for the hours of daylight and darkness for the three cloud ranges at Acklington/Boulmer in the north east of England. Figure 2.7 shows the percentage frequency of cloud amounts throughout the year at Acklington/Boulmer. These figures represent a typical north-east England weather (Meteorological Office 1984). Appendix A illustrates the daily meteorological observations obtained by Durham University Observatory for the years 1984 to 1988. Column 13 of the tables in the Appendix represent the cloud amount estimated in oktas (eights of sky) - 0 is completely cloudless and 8 is completely overcast. The meteorological data in Appendix A illustrates that there are very few cloudless days throughout the year.

From the agricultural viewpoint, the incidence of frost and the length of

Fig. 2.6 Average annual rainfall (mm) in County Durham over the period 1941-70



Source :- Modified from Climatological Memorandums 127 and 128, by the Meteorological Office (1984).

Figure 2.7 Frequency of Total Cloud Amount at Acklington/ Boulmer Over the Period 1957 - 76

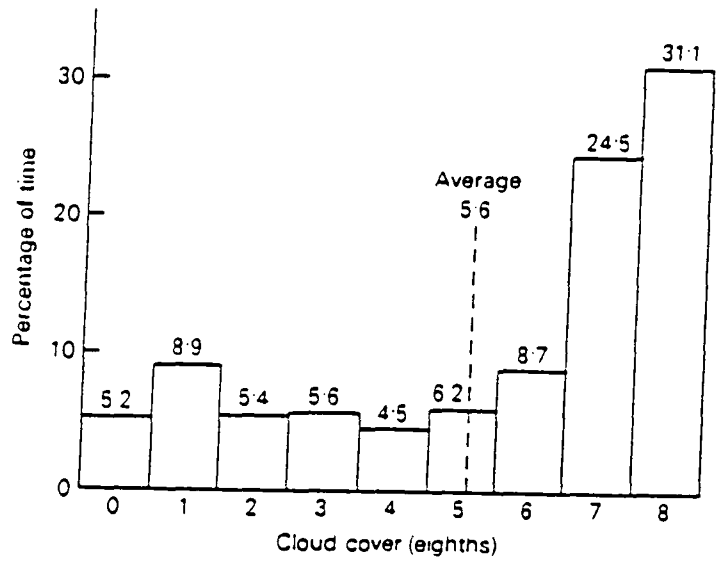


Table 2.2 Percentage Frequency of Hours With Total Cloud Amount in Selected Ranges at Acklington/Boulmer Over the Period 1957 - 76

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Eighths	Daylight hours												
0–2	15.2	13.7	12.1	12.3	11.4	14.1	10.9	12.9	13.2	13.1	16.3	17.8	13.3
3–6	24.0	25.1	26.1	28.3	30.0	31.6	28.5	30.7	29.2	27.4	26.6	25.7	28.3
7–8	60.7	61.2	61.7	59.4	58.6	54.3	60.5	56.3	57.5	59.6	57.2	56.4	58.5
	Hours of darkness												
0–2	25.4	25.0	24.7	27.8	24.1	22.3	20.4	25.5	27.6	24.4	28.5	30.1	25.7
3–6	19.1	19.3	19.9	18.9	23.4	27.2	26.7	24.3	20.8	21.7	21.4	21.7	21.8
7–8	55.4	55.7	55.4	53.4	52.5	50.6	52.8	50.2	51.8	53.6	50.1	48.1	52.6

the growing season remain as the most important temperature characteristics (Smith 1970). Taking the threshold of mean monthly temperature of 6.1 $C^{\circ}+$ as appropriate temperature for growth of most plants and applying it to the figures derived from the Durham University Observatory, the normal growing season lasts from about 229 days in lowlands to five and half months in the uplands (Smith 1970 ; Wong 1973 ; Brown 1978). Snow cover is affected by relief. The number of days of snow cover normally increases inland from the coast, depending on its depth. Also there is a considerable variation in snowfall from year to year. For example, in Durham between 1928 and 1947 the number of snow days varied from 10 to 44 (Smith 1970).

2.6. AGRICULTURE AND VEGETATION

The natural vegetation distribution in the area is a product of environmental and organic evolution. The vegetation changes as man affects the environment. As clear from figure 2.8, one of the most striking features of the vegetation is the sharp contrast between the moorland vegetation communities on the uplands to the west and the agriculture to the east of the County.

Despite the dominance of industry in the Durham economy, the appearance of the landscape is to a large extent agricultural (Warwick 1970). The agriculture sector is the biggest single employer in the County and the largest user of land. As seen in figure 2.8, most of this agricultural land lies in the east of the County. It can be seen from the image that the type of farming varies from the east to the west and this could be attributed to

- soil types,

- topography,

- climatic conditions.

Accordingly, the types of farming pursued in the County may be summarised in relation to three main regions (Warwick 1970):-

1. the East Region,

2. the Central Region,and

3. the West Region or the Dales.

As we move from the East to the dales ,

- the agricultural intensity declines,

- the size of the fields decreases to small parcels, and

- less land is devoted to the production of arable crops.

The east region contains the majority of land farmed on an intensive mixed pattern of cereals, potatoes, oil seed rape, milk and beef. The arable farms are concentrated mainly on the eastern dip slope of the Permian escarpment.

The central region extends to the westward as far as Staindrop where rainfall becomes a limiting factor (see figure 2.6) and this is as far as the corn belt extends. The conditions of soil and climate make this area suitable for the production of potatoes. This region is also important for grass with considerable investment in dairying and stock rearing.

The lowland area is mainly under grass dairying and stock rearing being the main farming practices. This area is characterized by small field sizes. In the early 20th century the only way to attract labour from the land to the expanding mines was to offer land in the form of small holdings, and this has given rise to the pattern of small farms (Warwick 1970).

In the Durham Dales most of the upland areas are open commons, although not all open moorland is common*. However, much open land is held freehold and is privately grazed by the owner occupier or tenant (Warwick 1970). The grazing of sheep on the hills is typical of this area. The environmental constraints in the west of the County mean that there are very real limits to farming practices.

The main arable crops farmed in the eastern area include cereals, potatoes, and oil seed rape. The arable farms produce wheat, barley, oil seed rape, and potatoes. These farms are concentrated mainly in the eastern and central regions of the County. Given the importance of these crops in to region's as well as country's agricultural economy, this study will investigate the use of Landsat-TM and ground data for their area estimation.

Field size is an important guide to the agricultural practices in the County and the area is characterised by the decreasing field sizes towards the west. Small fields and high attitude in the west make this area poor for arable farming. The majority of farmers in this region usually use the land for grazing with most of the land devoted to grass cultivation.

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* *The common lands are those subject to common rights. In English common law the common right is " a right, which one or more persons may have to take or use some portion of that which another man's soil naturally produces" (Campbell 1971).*

Agricultural Change

The main changes in the agricultural pattern in the area over the last few years are illustrated in table 2.3. There has been over the last 10 to 15 years, a polarisation between the arable farming in the east and the livestock farming in the west, each specialising more in their own sector. Arable farming has been revolutionised by technical developments such as the substantial shift to autumn sown crops. Because of modern fungicides and weedkillers it is now possible to plant wheat or barley in the autumn when the soil is dry. Pre-emergent spraying prevents weeds and fungicides stop mildew, which together help the crop through the winter. Such crops may grow to the 2nd or 3rd leaf stage by autumn and then lie dormant until spring when they grow well with split dressings of nitrogen. These techniques have doubled yields and resulted in earlier harvests. Winter barley can now be harvested by mid July, while spring barley is harvested in September.

Plant breeding has also been important, especially the development of dwarf wheat. This strain was mainly responsible for the increase in area planted by wheat. As illustrated in table 2.3 the area devoted to wheat has increased from 3,600 ha in 1977 to 13,500 in 1985. It also has a better price per ton than barley. Also the area of malting barley was reduced in Durham because of the climate. The increased area devoted to wheat has resulted in the reduction of the area cultivated by other crops such as root crops. Table 2.3*a* illustrates that the hectarage of root crops diminished because it became less attractive to the farmers due to the labour intensity of its production.

Fig. 2.8

Landsat False Colour Composite of County Durham

Bands 3(0.63 - 0.69 μm) 4(0.76 - 0.90 μm) 5(1.55 - 1.75 μm)

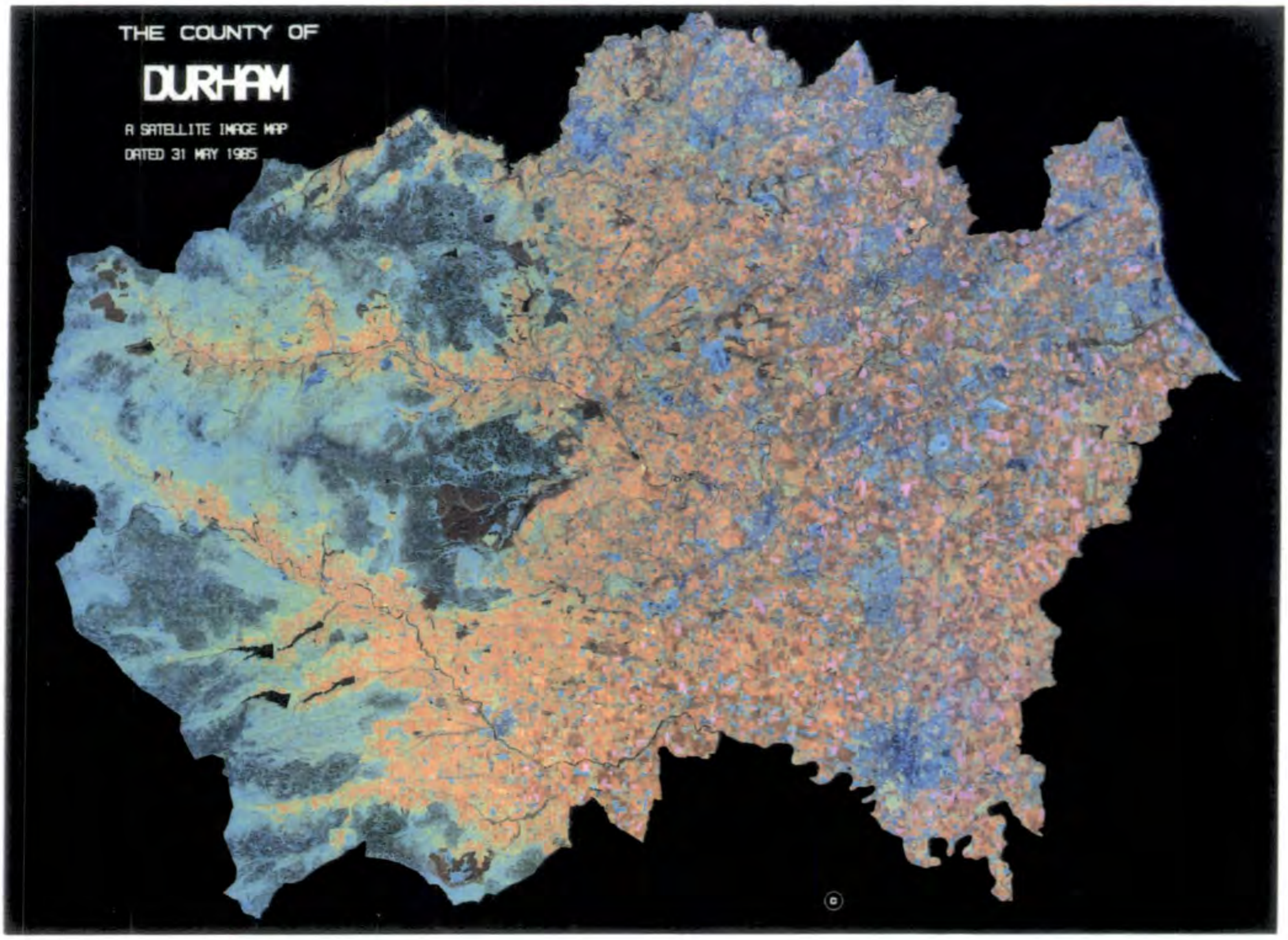


Table 2.3. Agricultural Change in County Durham.

a. Agricultural Area (ha)

Crop Type	1977	1985	% Change
Wheat...............	3,600	13,500	+277
Barley..............	28,300	20,700	-27
Oilseed Rape......	7	3,900	+55,641
Horticulture......	288	245	-15
Beans...............	32	94	+291
Other Stockfeed..	105	974	+928
Turnips/swedes..	1,186	536	-55
Beet/Mangold....	500	177	-64
Bare fallow........	524	214	-60
Woodland..........	1,672	2,026	+21

b. Type of Farm

Farm Type	1977	1985	% Change
Specialist dairy	230	184	-20
Mainly dairy.....	156	127	-19
Cattle............	169	107	-37
Sheep.............	51	87	+71
Cattle & sheep	349	352	+1
Poultry...........	19	17	-11
Pigs & poultry	40	33	-17
Cereals...........	61	89	+46
General cropping	117	95	-19
Vegetables.........	4	3	-15
Fruit.............	0	1	
Horticulture....	27	13	-52
Mixed.............	77	51	-34
Part-time.........	1128	1055	-6

Source: MAFF 1977, 1985.

Table 2.3*a* also shows that the area devoted to oilseed rape has increased dramatically since 1977. This is in part due to EC subsidies and is also because it is a useful crop to rest the soil. It takes out different nutrients from the soil and has a different root structure. It is a very good lead crop for wheat which makes wheat-wheat-barley-rape a common rotation practice in the region. Rape also can be mechanised using the same combine machinery as cereals. The crop is often preferred to root crops such as turnips and swedes whose production is very labour intensive.

The area of oilseed rape is going to be reduced following the introduction of new regulations by the CAP (Common Agricultural Policy) of the EC. Uncertainty over the level of subsidy prices following the introduction of a strengthened maximum guaranteed quantity system, together with the changeover to "double-low" varieties combined to discourage producers from planting the oilseed rape on the scale of the previous few years. For instance, reduced EC production of oilseed rape meant that a cut of 7.65 per cent was imposed in 1988 resulting in a price increase of 2.35 per cent compared with 1987 where a cut of 10 per cent was imposed (MAFF 1989).

The physical nature of the western region of the County makes it more appropriate for livestock farming. A new sheep breed called "mule" was mainly developed in this area. Farmers come from all over England to buy this mule sheep because of its breeding advantages and qualities. This is one of the factors that has led to the increase in the sheep farming by 71 per cent over the period from 1977 to 1985 (see table 2.3*b*).

2.7. SUMMARY AND CONCLUSION

The land use of the County may be seen as a response to its physical characteristics described in this chapter. This section outlines the main reasons for its choice as the study area. Following the brief outline of the physical context of the County, reasons for choosing the study area as the research site include the following:

- The Durham County represents a typical British and European agricultural area as :-

i. it represents a mixture of different agricultural practices

ii. it is characterized by small field sizes.

iii. it is a good example of the north European weather which characterised by cloud cover and regular rainfall throughout the year.

These characteristics make the County an appropriate region in which to test the feasibility of applying Landsat-TM for crop area estimation under European conditions.

- The location of the area in which the University is located, aided a comprehensive fieldwork programme.

- The region contains a good number of big farms which keep records of all the previous farming practices. A notable example being Houghall Farm which is owned by the Agricultural College and located just out of Durham City adjacent to the University. This farm among others was very helpful in checking the the accuracy of the information gathered or classified (see chapter 5).

- The farmers of the area are familiar with many researchers coming from the University studying different topics.

- The long experience of the Department of Geography with the area and its farmers.

- The availability of cloud-free Landsat-TM data for the study area.

CHAPTER 3

DATA SOURCES

3.1. INTRODUCTION

As stated in chapter one, the aim of this research is to develop a methods for estimating the crop type area in County Durham from the combined use of satellite imagery and field data. The most useful source of satellite imagery is derived from a multispectral sensor producing digital data for a large geographic area. A field data set was obtained by conducting a land cover survey using a stratified random sampling strategy. In order to understand the relationship between the digital numbers of the satellite image and the land use on the ground, and to select the optimum temporal, spectral and spatial parameters, the data sets were supplemented by other data sources such as aerial photography and Ordnance Survey Maps. These data sources are introduced and described in the context of this research.

3.2. FIELD SURVEY

The field data were obtained by conducting a field survey which took place between May and September 1988. Chapter four outlines in detail the methodology of field data collection, however, a stratified random sampling approach was applied in the study in order to collect the field data.

In remote sensing studies, field data is commonly used for the following purposes (Short 1982):

i. for selecting the training data sets for areas of known characteristics in supervised classification of digital data,

ii. for the interpretation of classes produced by unsupervised classification of satellite data, and

iii. for the assessment of the classification accuracy (see chapter 5).

In this study the principal reason for conducting a field survey was to produce estimates of crop type area using both the field and satellite data in a hybrid fashion. Also, the field data were important for selecting accurate training data for crops and land use. An assessment of the Landsat data classification accuracy was achieved by using the field data.

The study area was divided into five strata according to the criteria described in section 4.6. As stratified random sample was taken of approximately 3.1% of the study area in order to obtain field estimate of the agricultural crops on a sample unit basis. In the sampling process, the required number of units were selected at random from all the units of each stratum. The number of the SU's ranged from 7 to 11 in each stratum, and a total of 44 sample units were eventually selected.

Section 4.7 describes in detail the main steps which were taken before the carrying out the fieldwork. However, these steps included :-

- the design of an appropriate land-cover classification system for the study area,
- an understanding the agronomic nature of the crops being studied ,and
- the design of a questionnaire and annotation key to be used in the fieldwork.

Before visiting the field, the sample units were allocated on a map base, that is the exact location of a sample unit was translated into latitudinal and longitudinal coordinates. Then each unit was transferred from the Ordnance Survey (OS) maps to the aerial photograph (AP).

Once the sample units (SUs) were allocated a visit to the field took place. During the fieldwork period 44 sample units each $1.0km^2$ were visited. The questionnaire used in the field survey is listed in section 4.7.4. It contains three parts. The first section documents the physical characteristics of the sample units such as the topographic shape of the area, the amount of natural vegetation and soil colour. An annotation key is included in the second part of the questionnaire and the third part includes an aerial photography of the sample unit with an overlay in order to mark each cover type as well as any recent changes in the field boundaries. A brief discussion of the aerial photography-tracing technique to mark the land-cover type classes, will be presented in the subsequent section. Precise details about the methodology are presented in chapter four.

All the physical data were carefully checked and recorded in the questionnaire. Any recent changes found were marked on the overlays. Every farmer who owns a field in the sample unit was interviewed and asked for land use information for the year 1985. Many problems arose during these interviews, particularly the uncertainty from the farmers about the crops growing in their fields in 1985. Some farmers have no written records about their farms and so must rely upon a recollection of the previous three years. In the cases of those who implemented a crop rotation scheme on their farms it was easier for them to remember the crop types than those farmers who do not practice crop rotation.

Since 1971, when the aerial photographs were taken, some changes in the field boundaries have occurred. As mentioned earlier, this problem was addressed by recording any changes in the field boundaries at the time of sample unit inventory. Also, any other major changes were recorded when they existed. In some sample units there were some fields belonging to a farm located few miles away. As will be explained in chapter four, this problem increased the time devoted to the inventory of that particular sample unit.

Once the field visit was completed the area of each land-cover was measured in the laboratory. Following this, the statistical analysis was applied in order to produce the crop type area estimate on a stratum by stratum basis. The results were then aggregated to obtain an estimate on the County basis.

3.3. AERIAL PHOTOGRAPHY

Aerial photography (AP) was the first method of remote sensing, which began as early as the 1880s when the first air photo was taken the Arc de Triomphe and the Place de l'Etoile in Paris using a plate camera by F. Nadir from a hot-air balloon. Even today in spite of the developments in satellite remote sensing, aerial photography still remains the most widely used type of remotely sensed data because of its availability, economy, synoptic viewpoint, time freezing ability, spatial resolution (Curran 1985). Additional advantages of aerial photography are the use of stereo pairs which adds another dimension to the coverage (Lo 1986), and a greater geometric fidelity.

APs have been widely used in agricultural studies for crop identification and crop diseases (Myers 1983). When combined with the satellite imagery they give a higher accuracy than satellite data alone. Most of the major agricultural remote sensing programmes used aerial photography to supplement ground data where fieldwork was not possible.

In remote sensing, aerial photography has two main roles; cartography and reconnaissance (Colwell 1983). In this research, APs were used for the following tasks:-

- to transfer the sample units from the Ordnance Survey maps to the ground accurately, and

- to measure the area of each land cover type, and to assist in field mapping.

The most recent aerial photography available for the study area was taken by the B. K. S. Surveys in 1971 at a 1:10,000 scale. These were the only APs which covered the whole County. Despite their age, they were of a good quality and provided the basis for field work planning and implementation.

Prior to each field visit a map of the sample unit was drawn by using an overlay on the aerial photograph. Because of the good quality of the AP, the boundaries between fields were sharply defined and could be mapped accurately. The majority of these boundaries have not changed significantly since 1971. The author was aware of these changes as well as other changes resulting from deforestation or the opencast mining. Figure 3.1 shows how the overlays were produced. Although great care was taken in this exercise it is impossible to accurately place a line on a map where in reality there is no exact boundary, but rather a transition. Chapter four

Figure 3.1

Example of the Aerial Photography Used in the Study

Scale 1:10,000 (reduced for inclusion here)

Source : B.K.S Surveys

describes the technique by which APs were used to allocate the sample units in the field and to estimate the area of each land-cover type in the sampling unit.

3.4. Ordnance Survey Maps

The map data used for this research was the 1:50,000 second series Ordnance Survey (OS) maps dated 1976. The study area is covered by sheet maps number 87, 88, 92 and 93. These maps contain $2cm^2$ cells which represent the British National Grid $1km^2$

The OS maps were used to design the sampling frame for the study area. Since the size of the sampling units was determined as 1 km^2 (see section 4.4), the National Grid on OS maps provided convenient units for the sampling frame. This is shown by figure 3.2.

For the areas with no aerial photography coverage 1:25,000 OS maps were used as field boundaries are clearly shown on these maps (see figure 3.3). Only two sample units had no aerial photographic coverage because the area had not been covered by the 1971 B.K.S aerial survey.

Figure 3.2

A Part Of 1:50,000 OS Map Sheet No. 93, Showing Some of the Sample Units Distribution.

Figure 3.3

A Part of 1:25,000 OS Map Sheet No. NY 82/92

Showing Field Boundaries

Source : Ordnance Survey (1981).

3.5. LANDSAT SATELLITE DATA

3.5.1. Introduction.

Section 3.5.2 will outline the source of the satellite data used for this study. The subsequent sections will give a brief description of the Landsat series and illustrates the Landsat data types in general. Since the Landsat-5 Thematic Mapper data were used in this research, section 3.5.4 will describe in detail the nature of the data and compare between TM and other Landsat data types. Also, the main reasons behind choosing Landsat-TM for this project will be discussed.

3.5.2. Data Set

Single date Landsat-5 TM data acquired on 31 May 1985 were used. The path/row annotation of these data is 203/22 (see figure 3.4). The data were acquired from EOSAT in a digital form stored stored on Computer Compatible Tapes (CCTs). Also the data were used in a photographic form as an enhanced false colour composite (EFCC) hard print.

The EFCC image was obtained by assigning Thematic Mapper (TM) bands 3(0.63 - 0.69 μm), 4(0.79 - 0.90 μm) and 5(1.55 - 1.75 μm) to the blue, red and green (see figure 2.8). The term false is used because the wavelength of the bands used do not exactly correspond to the colours by which they are displayed. As will be discussed in chapter 4 and 5, the EFCC can provide a valuable information on the land cover in a hard copy form. This was an important source for sampling frame design. It also was helpful in choosing the training sites and testing the classification accuracy.

Figure 3.4

Ground Coverage of TM Scenes for U.K. (NRSC)

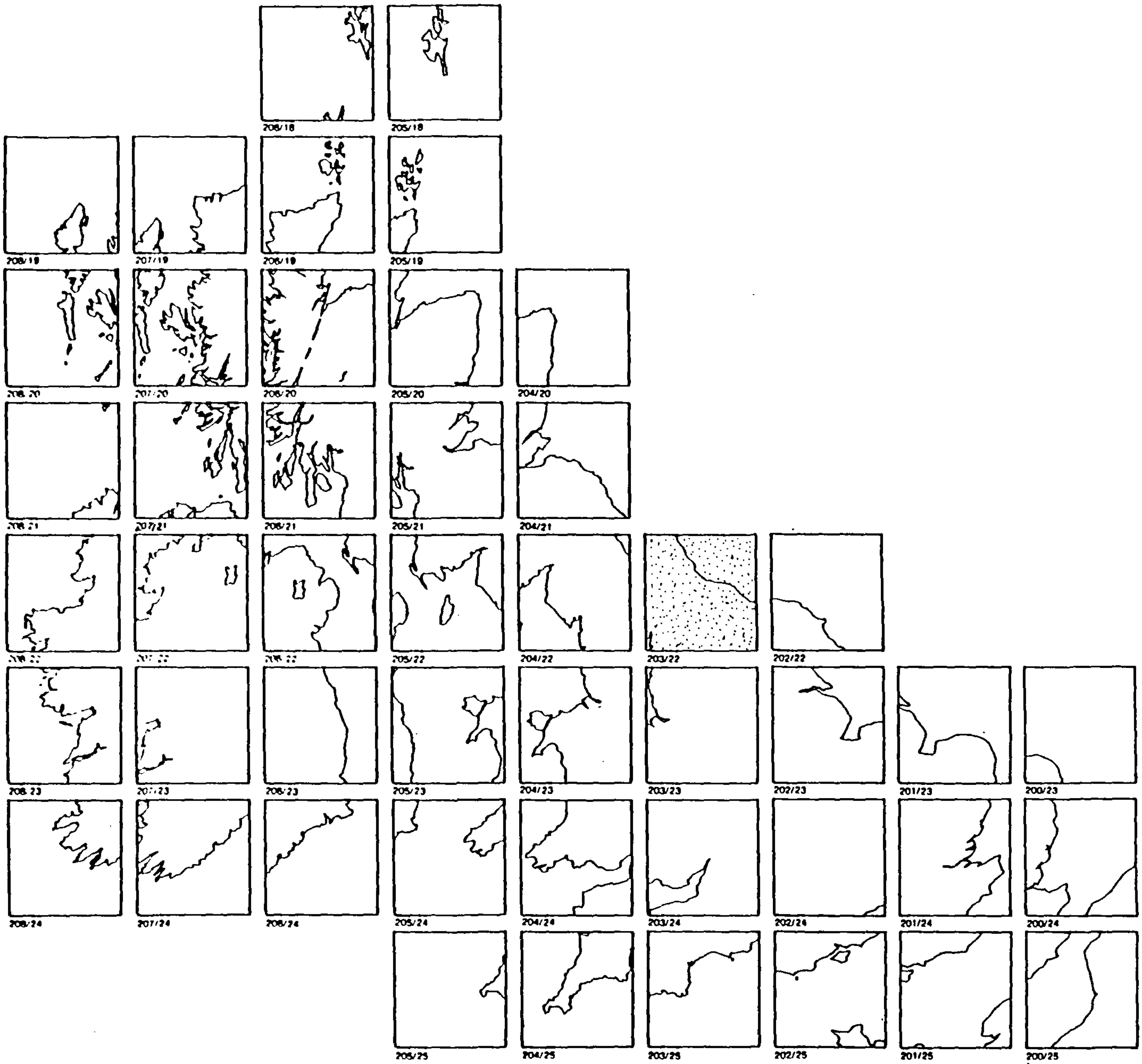
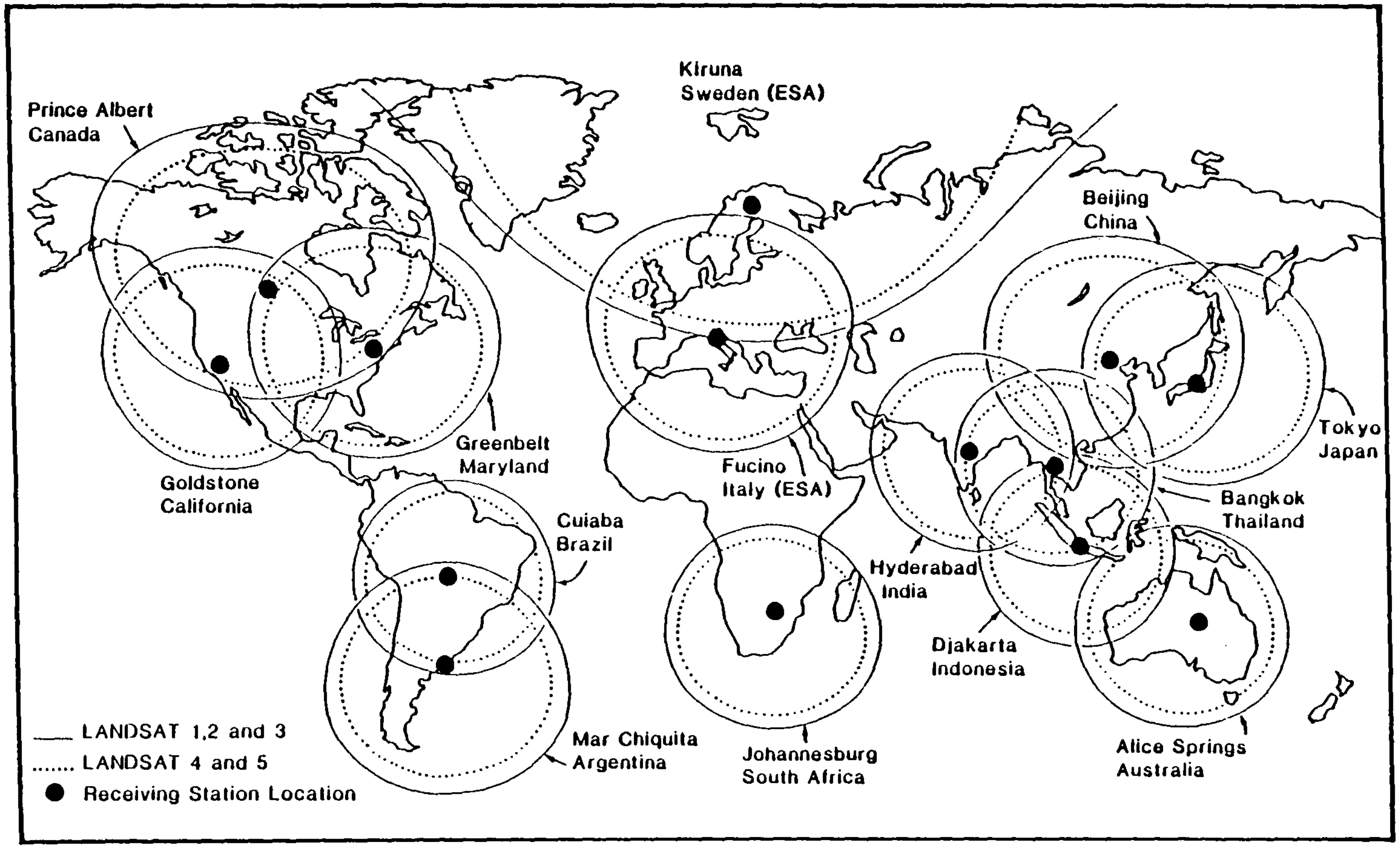


Figure 3.5

Location of Landsat Satellites Ground Receiving Stations



3.5.3. Landsat Series

Landsat series satellites have provided valuable geographical data from sensors giving high resolution images and repetitive coverage of the globe. The Earth Resources Technology Satellite (ERTS) was the first name for the programme. In 1975, the ERTS programme was renamed as Landsat. The Landsat was operated by NOAA until September 1985, when the programme was sold to the Earth Observation Satellite (EOSAT) company. The Landsat series has two main generations.

First Generation

This generation included Landsat-1, 2, and 3. On July 23rd 1972, Landsat-1 was launched by a Thor-Delta rocket, and operated until January 1978. Landsat-1 was a modified Nimbus weather satellite. On January, 22, 1975, Landsat-2 has launched. The Landsat program was continued by the launch of Landsat-3 on March,5,1978. The first generation of Landsat carried two types of sensors:-

(a) Return Beam Vidicon (RBV), and

(b) Multispectral Scanner System (MSS).

(a) Return Beam Vidicon (RBV)

Return Beam Vidicon (RBV) television cameras were carried on Landsat-1, and 2. On Landsat-1 and 2 three RBV cameras used, while only two were carried by Landsat3. RBV sensor had the following spectral bands:-

Band one 0.480 - 0.580 μm (green)

Band two 0.580 - 0.680 μm (red)

Band three 0.690 - 0.830 μm (reflected infrared).

The RBV on Landsat-1 and 2 was not successfully operated. It was turned off in August 1972 due to some power problems. RBV operated for only 45 hours. The images produced by RBV covered an area of 185 km by 185 km and had a ground resolution of 80m.

(b) Multispectral Scanner System (MSS)

The MSS was carried by Landsat-1, 2, and 3. The image produced by MSS has a 79m ground resolution and covers a ground area of 185 km by 185 km. The MSS is capable of imaging the earth's surface in four spectral bands simultaneously through a single optical system (see table 3.1) There are six detectors for each band so that altogether 24 detectors are used for MSS (Slater 1980). Each one of these detectors converts the recorded radiance into a continuous electrical signal which is then sampled at fixed time intervals and converted to a 6 bit number (0-64) which either recorded onto a magnetic tape or transmitted down to the earth. The MSS has successfully operated for 7,462 hours on Landsat-1. It was also the main sensor carried on Landsats-1, 2 and 3.

Landsat-3 was launched on March,5,1978, with two main improvements in its design. First, a thermal band (10.40-12.60μm) was added to the MSS system. This band failed shortly after launch as a result of technical problems. The second main change in the design of Landsat-3 was an improvement of the spatial resolution of the RBV system. This was achieved by introduction of two-camera broad-band, rather than multispectral system.

When Landsat was launched in 1972, there were only three ground receiving stations in the USA and one in Canada. The first generation of Landsat satellites transmitted their data through the nearest ground receiving station. If there was no receiving station nearby, data were stored on magnetic tapes to be played-back to a receiving station.

Second Generation

Landsat-4, the first of the new generation of Landsat satellites, was launched on 16, July, 1982. On first of March 1984, Landsat-5 was successfully launched. It has the same orbital parameters as Landsat-4 and is 8 days behind Landsat-4 in its orbital path. These satellites enabled the collection of images of each area on the Earth's surface once every 16 days compared to the 18 day cycle of Landsat-1, 2 and 3. Landsats 4 and 5 carry same sensors as the first generation, apart from three main differences:

i) The pixel size of the MSS sensor in the first generation was 79m by 79m but in the second generation it was changed to be 80m by 80m.

ii) The MSS band numbers have renamed 1,2,3 and 4 instead of 4,5,6 and 7 , and

iii) The major difference was the introduction of a new sensor called the Thematic Mapper (TM), giving an increased coverage of spectral bands between 0.45 and 12.5 μm , that is from the visible to the thermal infrared.

Table 3.1

MSS Spectral Bands and Principal Application.

Band No.*	Band Name	Band Width μm	Application
4	green	0.50 - 0.60	Emphasise the movement of sediment laden water and aided delineation of shoals and reefs in shallow water.
5	red	0.60 - 0.70	Emphasised cultural features including urban areas
6	Near Infrared	0.70 - 0.80	Emphasised vegetation and the boundaries between landforms, land and water.
7	Near Infrared	0.80 - 1.10	Provide the best penetration of atmospheric haze and emphasise the same features as band 6.

* *The band numbers were renamed to 1,2,3 and 4 on Landsats 4 and 5.*

As mentioned earlier, all first generation of Landsat satellites had tape recorders to record the data they collected.The second generation Landsat satellites have also carried tape recorders, but when out of range of a receiving station it has been possible to transmit the data to a receiving station in White Sands, New Mexico via a US communication satellite called the Tracking and Data Relay Satellite (TDRS) (NASA 1982c). Figure 3.5 shows the world location of Landsat satellites ground receiving stations.

The Landsat-4 and Landsat-5 systems provide image data of significantly better geometric fidelity than were obtained from first generation Landsat missions(Welch *et al* 1985) primarily because the introduction of the TM sensor. The greater information content in both spatial and spectral dimensions provides the basis for improvements in monitoring and evaluating agricultural resources. Section 3.5.4 describes in detail the nature of the TM data and its application to agriculture. It also shows the advantages of TM data over MSS data.

3.5.4. THEMATIC MAPPER

The Thematic Mapper (TM) is a scanning optical sensor operating in the visible and short wave infrared parts in the electromagnetic spectrum (see table 3.2). The TM sensor was in part designed to maximise vegetation sensing capabilities for agricultural applications. Several authors including Barker (1983) , Beyer (1983) , Anuta *et al* (1984), Barker (1985) and Townshend *et al* (1988) provide detailed descriptions of the Thematic Mapper data. Table 3.2 illustrates the Thematic Mapper spectral bands and their applications. Figures 3.6 to 3.11 represent a 512×512 pixel subscene of TM bands 1, 2, 3, 4, 5 and 7 showing Durham City and the River Wear.

The main improvements in TM over MSS include two additional spectral bands, increased sensor radiometric performance, and increased spatial resolution. The significant improvement associated with the TM's spectral resolution was the introduction of two short wave infrared bands, i.e. band 5 (1.55 - 1.75 μ m) and band 7 (2.08 - 2.35 μm). The spatial resolution of TM as measured by IFOV is 30m compared with the corresponding value of 79m for the MSS. The radiometric sensitivity of MSS is 6-bits, so that observed data are quantised onto 64 levels ranging from 0(black) to 63(white). For TM, the digital data are quantised on an 8-bit (0-255) scale before transmission. Table 3.3 summarises the main differences between MSS and TM data.

Detailed studies of Landsat-TM data quality were conducted by a number of authors (Barker 1983 ; Beyer 1983 ; Bizzel and Prior 1983 ; MacDonald *et al* 1983; Quattrochi 1983 ; Sandousski *et al* 1983 ; Anuta *et al* 1984 and Townshend *et al* 1988). TM data were found to be significantly better than MSS data for specific applications by all these investigators. For example, agricultural crop classification accuracy was increased by using Landsat TM compared with MSS. Quattrochi (1983) compared agricultural crop classification accuracy derived from a multitemporal MSS data set with a single date TM scene. He found that single date TM results improved classification accuracy by 17% over the equivalent multitemporal MSS data.

The usefulness of the additional two short wave infrared SWIR TM bands (band 5 and 7) for the agricultural application was studied. MacDonald (1983) carried out a classification of soybeans using TM data, both with and without the SWIR bands. They have found that the classification accuracy of soybeans increased by 25% when TM bands 5 and 7 were used (MacDonald *et al* 1983). Bizzell and Prior (1983) have found that the best bands for the separability of agricultural classes always included at least one band from the visible, NIR and SWIR region. They reported that when no SWIR band was used in the classification, the overall performance was significantly degraded (Bizzell and Prior 1983).

In summary, the increased number of spectral bands and the improved quantisation capabilities afforded by the TM sensor design have led to a significant improvement in classification accuracies attainable relative to MSS. As a result of these improvements, TM data can be extremely valuable for crop type and area proportion estimation, and agricultural land use surveys.

Table 3.2. TM Spectral Bands and Their Applications

Band No.	Band	Width μm	Application
1	blue-green	0.45 - 0.52	-Designed for water body penetration, making it useful for coastal water mapping. Also useful for differentiation of soil from vegetation, and deciduous from conferous flora.
2	green	0.52 - 0.60	-To measure visible green reflectance peak of vegetation for vigor assessment. Ratio 2/4 limonitic rock mapping and for redness on desert sand.
3	red	0.63 - 0.69	-A chlorophyll absorption band, important for vegetation discrimination. Ratio 3/4 geobotanical relationships. Lithological separation (iron rich rocks) and structural studies.
4	Near Infrared	0.79 - 0.90	-Useful for determining biomass content and for delineation of water bodies. Reconnaissance mapping and geobotanical studies.
5	Short wave Infrared	1.55 - 1.75	-Foliar moisture. Lithological mapping, bedrock/ drift separation. Soil moisture mapping. Ratio 4/5 separates hydrous and iron rich rocks, ratio 5/7 for clay mineral differentiation.
6	Thermal	10.4 - 12.5	-Use for vegetation stress analysis and evapotranspiration.Soil moisture discrimination and thermal mapping of sediments. Ground water studies, topographic mapping and extraction of sub-surface anomalies. Bathymetry of lakes and discrimination of silicious rich rock.
7	Short wave Infrared	2.08 - 2.35	-Designed for discriminating rock types and for hydrothermal mapping.

Source: Townshend *et al* (1988) and Freden & Gordon (1983)

Figure (3.6) TM Band 1 (0.45 - 0.52 μm)

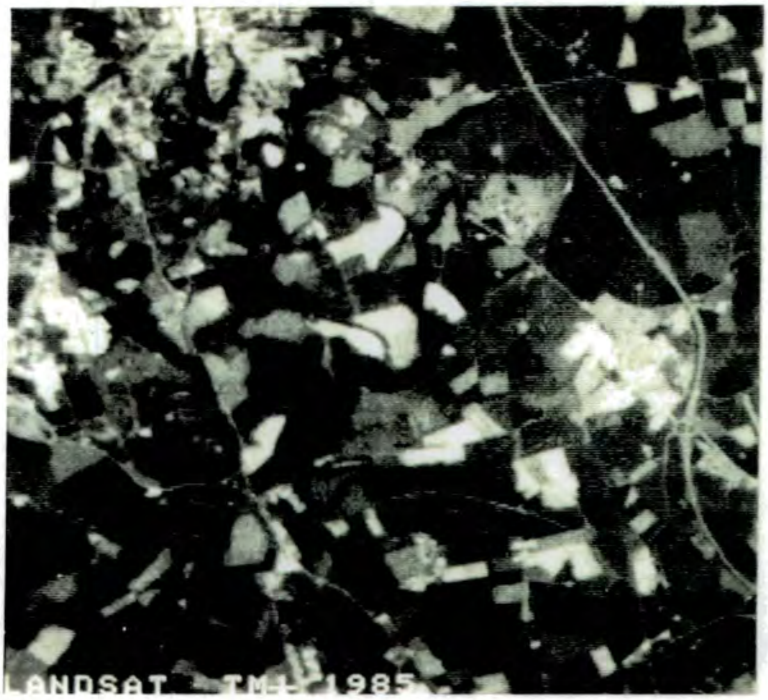


Figure (3.7) TM Band 2 (0.52 - 0.60 μm)

Figure (3.8) TM Band 3 (0.63 - 0.69 μm)

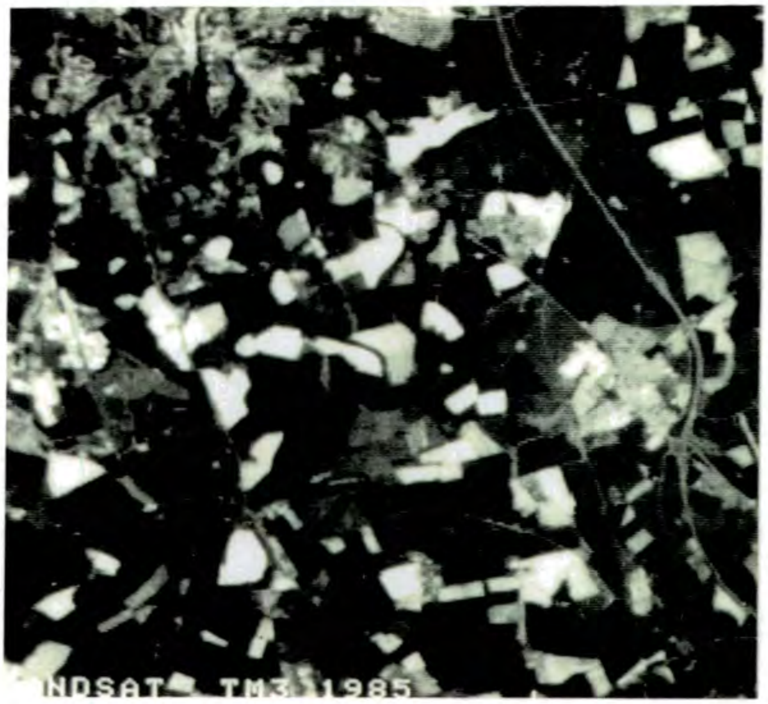


Figure (3.9) TM Band 4 (0.79 - 0.90 μm)

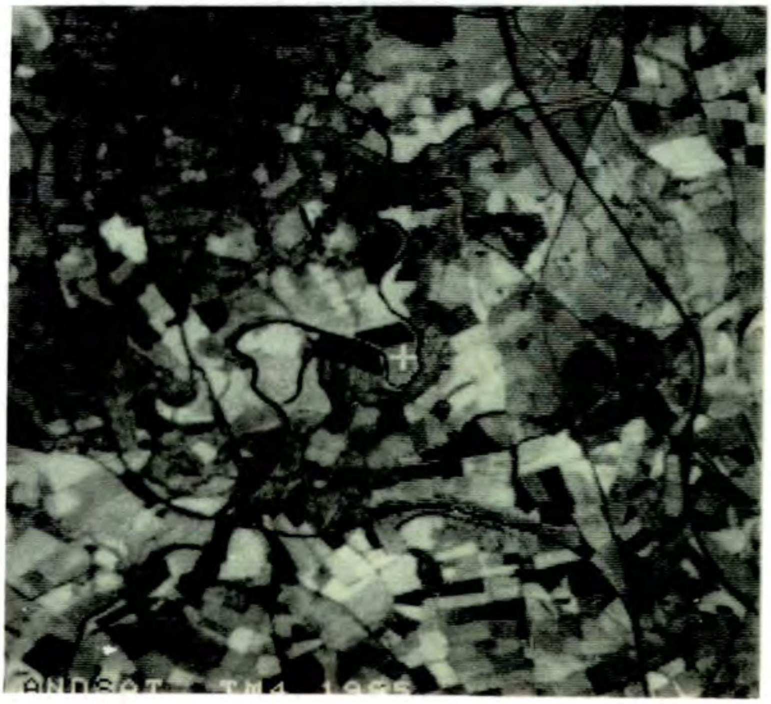
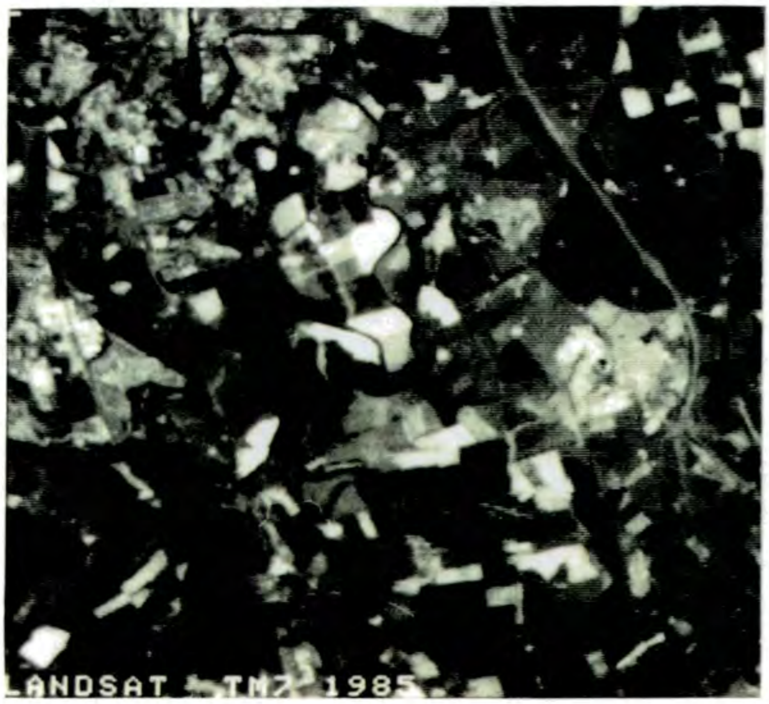


Figure (3.10) TM Band 5 (1.55 - 1.75 μm)

Figure (3.11) TM Band 7 (2.08 - 2.35 μm)



The increased spatial resolution of TM sensor over MSS makes it more appropriate to survey agricultural areas with small field sizes such as those in Europe and U.K. The poor spatial resolution of Landsat MSS has tended to generalise digital records particularly where fields are smaller than the pixel size.

Table 3.3

Comparison between MSS and TM.

MSS	TM
-Carried on Landsat 1,2,3,4 and 5	-Carried on Landsat 4 and 5 only
-4 spectral bands in visible and and near infrared	-6 bands in visible and short wave infrared and one band in thermal infrared
-79m spatial resolution (IFOV)	-30m spatial resolution for all bands except thermal infrared band which has 120m IFOV
-Has 6 detectors	-It 16 detectors except band 6 with only 4
- it is active only in the forward scan motion of the mirror	-Scans in both directions (forward and backwards).
-Has 64 gray levels	-Has increased radiometric sensitivity with increased grey level range to 256.

3.5.4. FACTORS INFLUENCING REFLECTANCE MEASUREMENTS OF AGRICULTURAL CROPS

In recent years considerable progress has been made towards the use of remote sensing technology to estimate crop acreage and predict yield. One of the main problems facing the application of this technology in the agricultural field is the deviation of a crop from its expected spectral reflectance. This deviation is mainly due to the influences of environmental and cultural factors. A considerable number of studies have investigated these problems (Suits 1972; Colwell 1974; Dugg 1977; Kollenkark et al 1981a; Kollenkark *et al* 1981b; Bauer *et al* 1981; Walburg *et al* 1981; Kollenkark *et al* 1982; Crist 1982; Daughtry *et al* 1982; Curran 1983; Asrar *et al* 1985; Lord and Desjardins 1985; Shibayama and Wiegand 1985; Ranson *et al* 1985; and others).

All these studies have shown that the spectral reflectance of crops is influenced by many factors including:-

(a) Environmental Influences include:-

i) solar angle

ii) clouds

iii) winds

iv) haze

v) soil moisture

vi) diseases and pests

vii) canopy geometry

(b) Cultural Practices which include:-

viii) date of planting

ix) row spacing and direction

x) time of irrigation

xi) fertilization

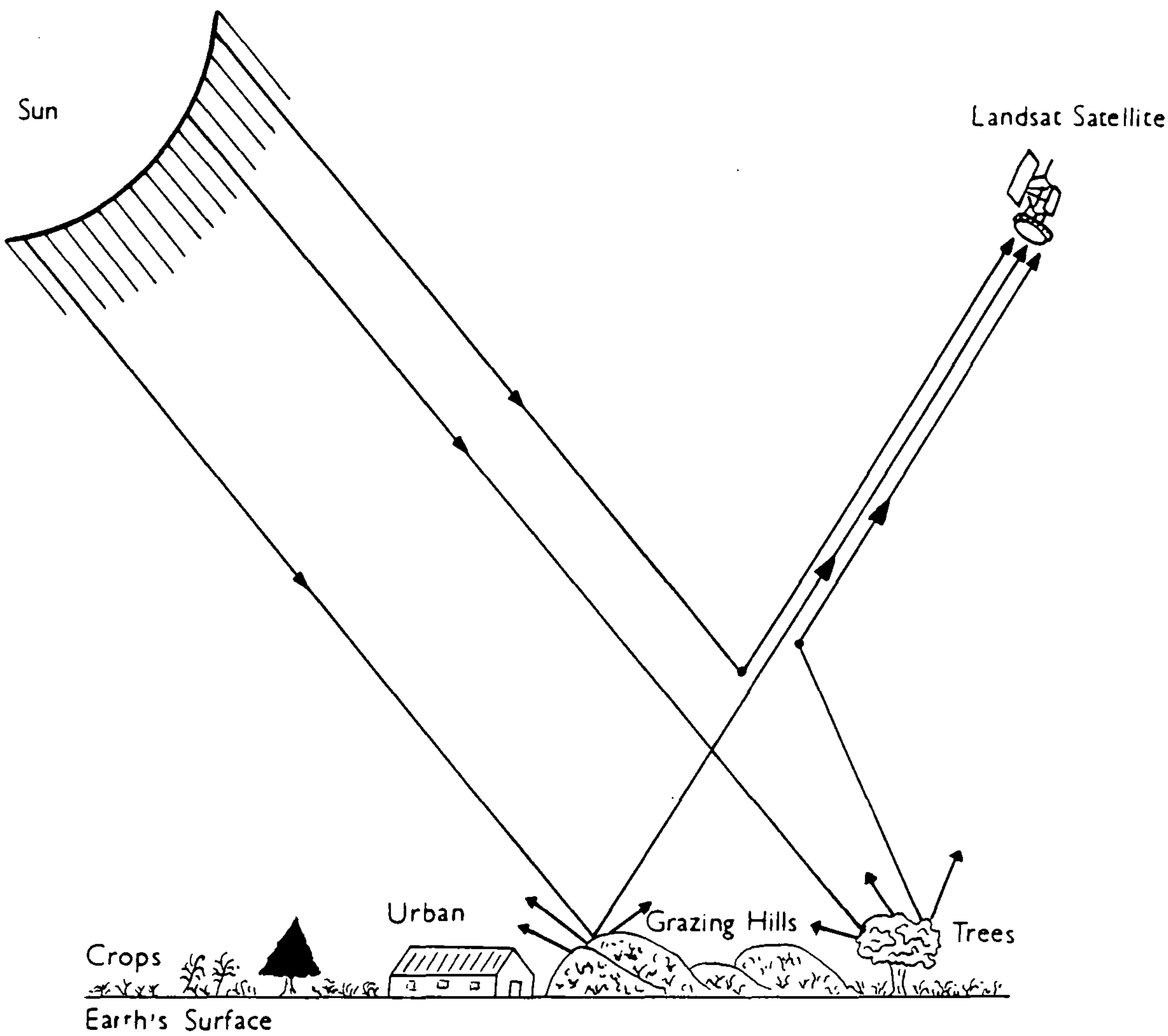
xii) crop variety

xiii) plant population

Reflected radiation received at a satellite sensor has passed twice through the atmosphere, once on its journey from the sun to the surface of the Earth and once after being reflected by the surface of the Earth back to the sensor (Mather 1987). Electromagnetic radiation is absorbed and scattered by atmospheric gases, water vapours , haze, dusts, and industrial smokes. These atmospheric factors reduce the amount of radiation received by the sensor from the object being sensed, and hence affect the image quality. This is shown in figure 3.12. As a result of the atmospheric effects, the radiation reflected by the tree is scattered to point S1, so it is sensed by the sensor as if it is coming from the grazing hill. Also, the atmosphere has scattered the radiation coming from the sun at point S2, which is sensed by the sensor as it comes from the grazing hill too as shown in figure 3.12, in both cases the radiance appears as if it was reflected from one object (grazing hill), but in fact the radiance was reflected by two different objects on the ground (Mather 1987). These effects cause an atmospheric distortions to the quality of the satellite data. This in turn affects the classification accuracy of the data.

Because of these distortions, atmospheric correction of Landsat data might be necessary; this will be discussed in chapter 5. Haze had a minor effect on the Landsat-TM data used in this study. Fortunately, its effect was only on a small part of the study area as it is shown in figure 2.8.

Figure 3.12 The Mechanism of the atmospheric effects on the signal received by Satellite mounted sensor



Source: Modified from Mather (1987)

In his study on the effects of cultural practices on the spectral reflectance of soybeans and corn, Crist (1982) concluded that both nitrogen fertilization and decreased row spacing tend to raise the peak green reflectance value of corn, while early or late planting and decreased planting density tend to lower the peak soybean green reflectance value. Kollenkark *et al* (1981b) have carried out a study on the effects of different cultural practices on the spectral reflectance of soybeans. They indicated that several cultural practices cause differences in soil cover, LAI, and biomass, which in turn were manifest as spectral reflectance characteristics of soybean canopies. Walburg *et al* (1981) studied the effects of different nitrogen level treatments on spectral reflectance of corn canopies. They showed that agronomic changes in canopies caused by different levels of nitrogen treatment resulted in detectable reflectance variations. They indicated that reduced leaf area, biomass, and soil cover lowered chlorophyll content and decreased plant height were among the effects seen in nitrogen-deprived canopies as canopy reflectance variations (Walburg *et al* 1981).

The effects of cultural and environmental factors on the reflectance of the spring wheat were investigated by LACIE (Bauer *et al* 1981a). The main factors studied were soil moisture, planting date, nitrogen fertilization and cultivar (crop species). Figure 3.13 illustrates the relationships between these factors and the spectral reflectance of spring wheat. The amount of fertilization affects the greenness and brightness of the plant and in turn influence its spectral reflectance. Bauer *et al* (1981a) found that the effect of nitrogen fertilization and soil moisture on the crop growth and spectral response were significant. They indicated that the plant date and cultivar also influence the spectral response of spring wheat (Bauer *et al* 1981a).

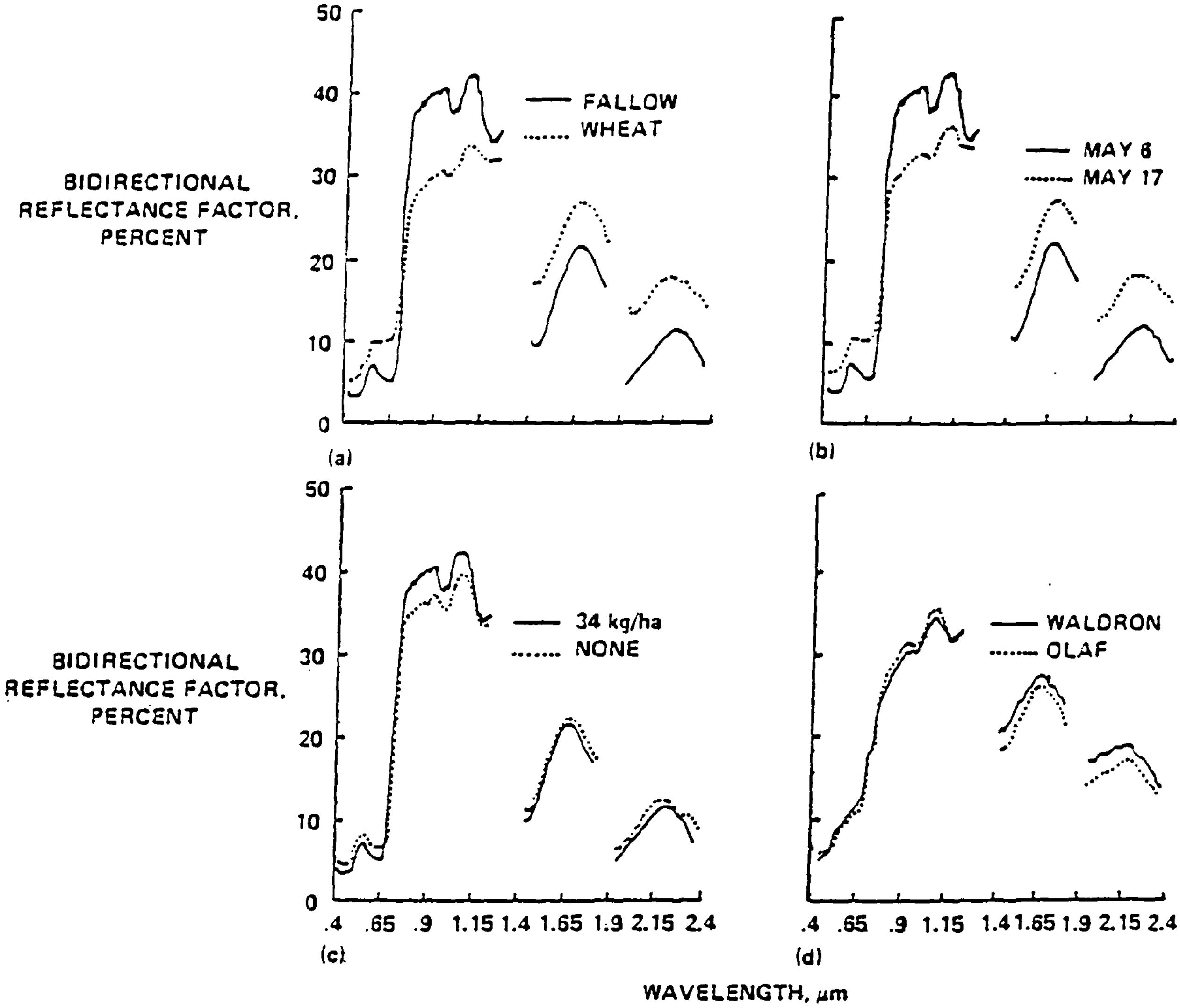
To utilise remote sensing data effectively, it is necessary to understand the effects of the interactions between solar illumination and crop canopy. Numerous field studies have investigated the effects of changing sun angle on vegetation canopy reflectance (Suits 1972; Colwell 1974 ; Kollenkark *et al* 1981a; Kollenkark *et al* 1982; Daughtry *et al* 1982; Kimes 1983; Ranson *et al* 1985; Shibayama 1985). Many of these studies have found that the measured reflectance factor of plant canopies is a function of plant geometry, sun angle and view angle. The effects of these factors differ from the canopies with no horizontal spatial variation to those with horizontal variation.

Most of the research studies in this field have concluded that the row direction has a significant influence on the reflectance of agricultural crops. Suits (1972) has concluded that the reflectance factor increases as the sun elevation increases. This occurred as a result of the changes in the amount of shadow within the canopy.

The influence of the row direction upon reflctance depends upon wavelength. Many of the studies conducted on this subject have shown that significant increases in the near infrared can occur with decreasing sun elevations (Duggin *et al* 1977; Kollenkark *et al* 1981a). By using both red (0.6-0.7μm) and near-infrared (0.8 - 1.1μm) wavebands for investigating the effects of solar illumination angle on soybean canopy reflectance, Kollenkark *et al* (1982) reported large relative changes in reflectance from the 0.6 - 0.7μm wavelength band as a function of solar zenith and azimuth angles, while only small relative changes were evident in the 0.8-1.10μm band. These effects are illustrated in figure 3.14.

Figure 3.13

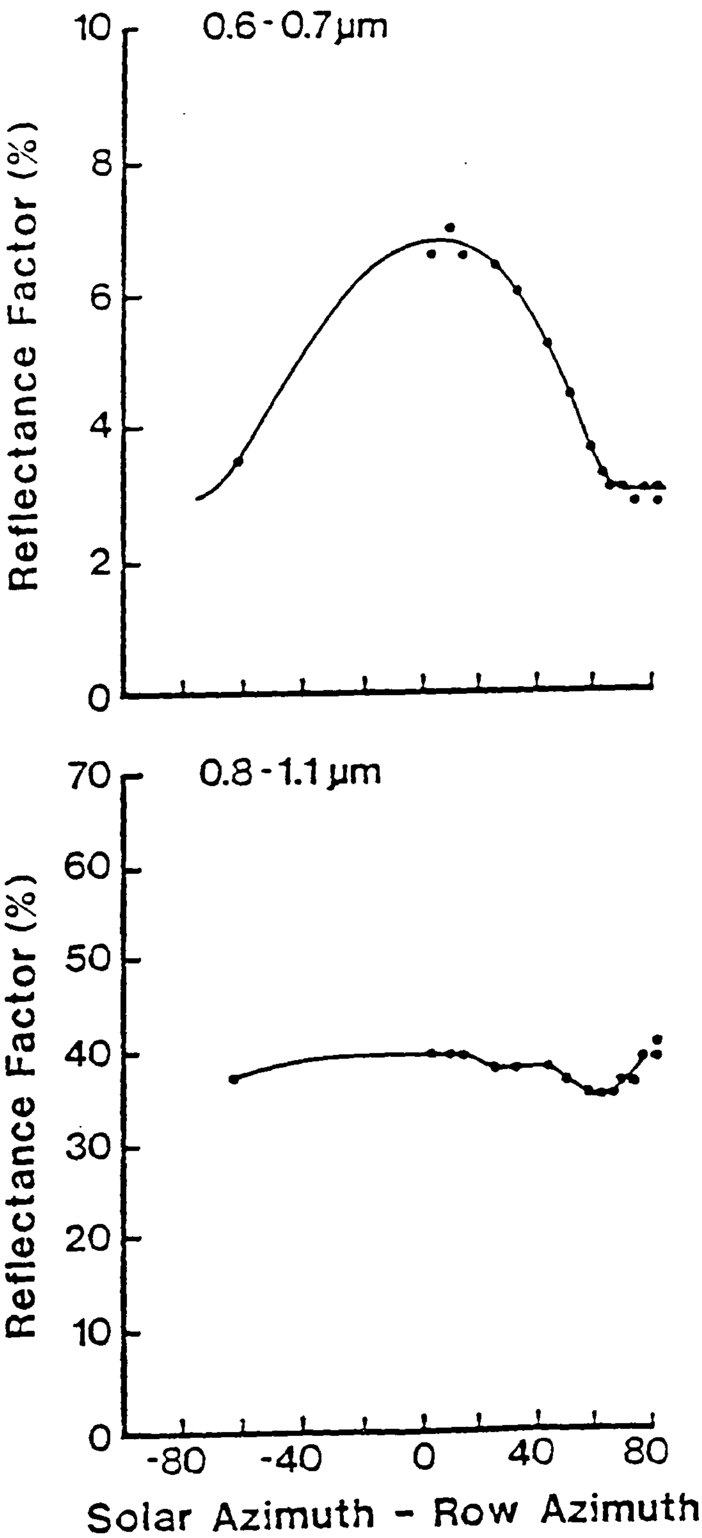
Effects of cultural factors on the spectral reflectance of spring wheat, a) previous crop b) planting date c) nitrogen fertilization d) cultivar



Source: Bauer *et al* (1979)

Figure 3.14

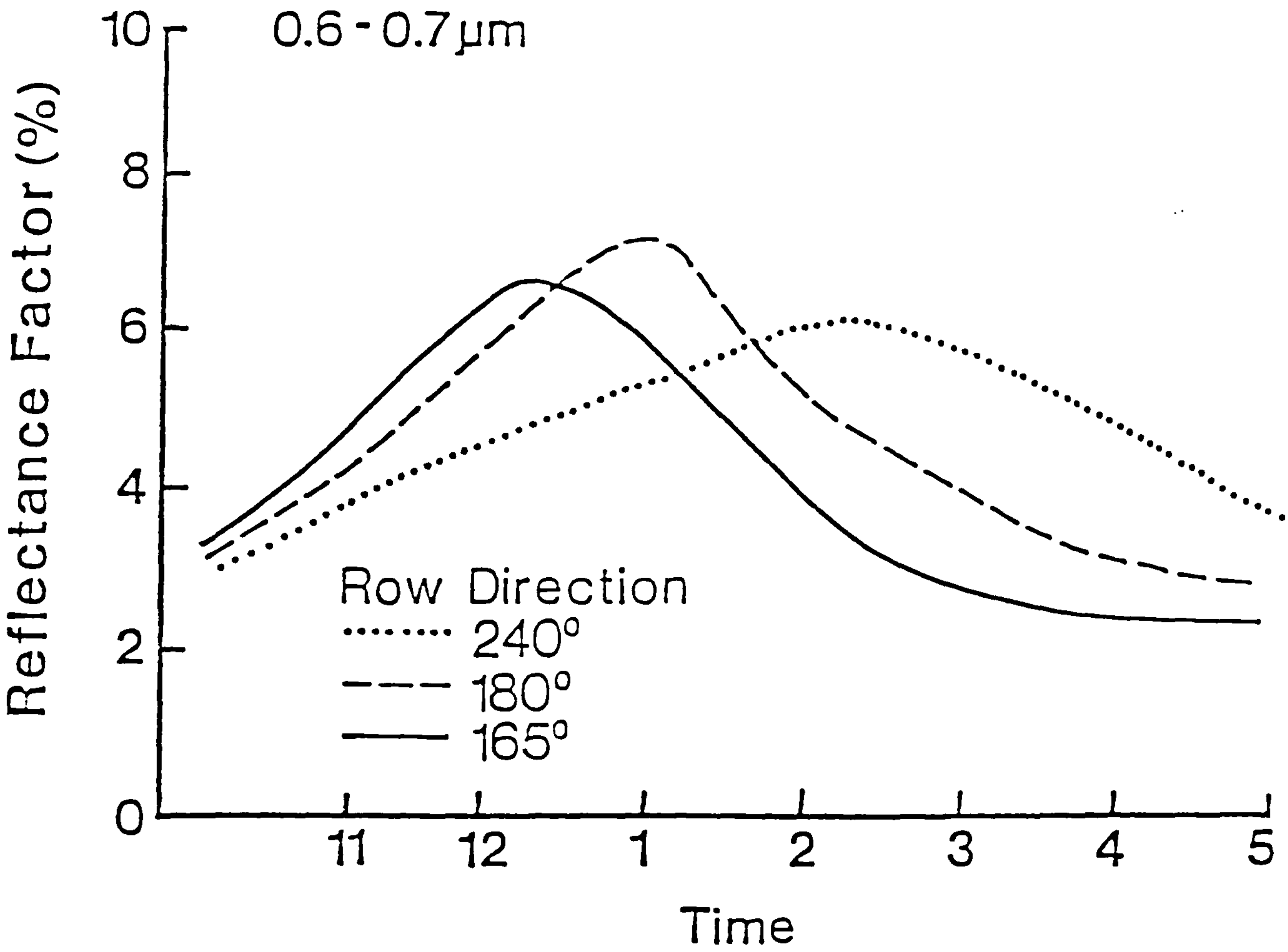
Changes in the reflectance factor in red band (0.60-0.70μ m) and the infrared band (0.80-1.10μ m) plotted against the difference between solar and row azimuth. Row azimuth=180°



Source: Kollenkark *et al* (1981a).

Figure 3.15

Reflectance factor in the red wavelength region (0.60 - 0.70μ m) for three row directions over time on August 12, 1979.



Source: Kollenkark *et al* (1981a).

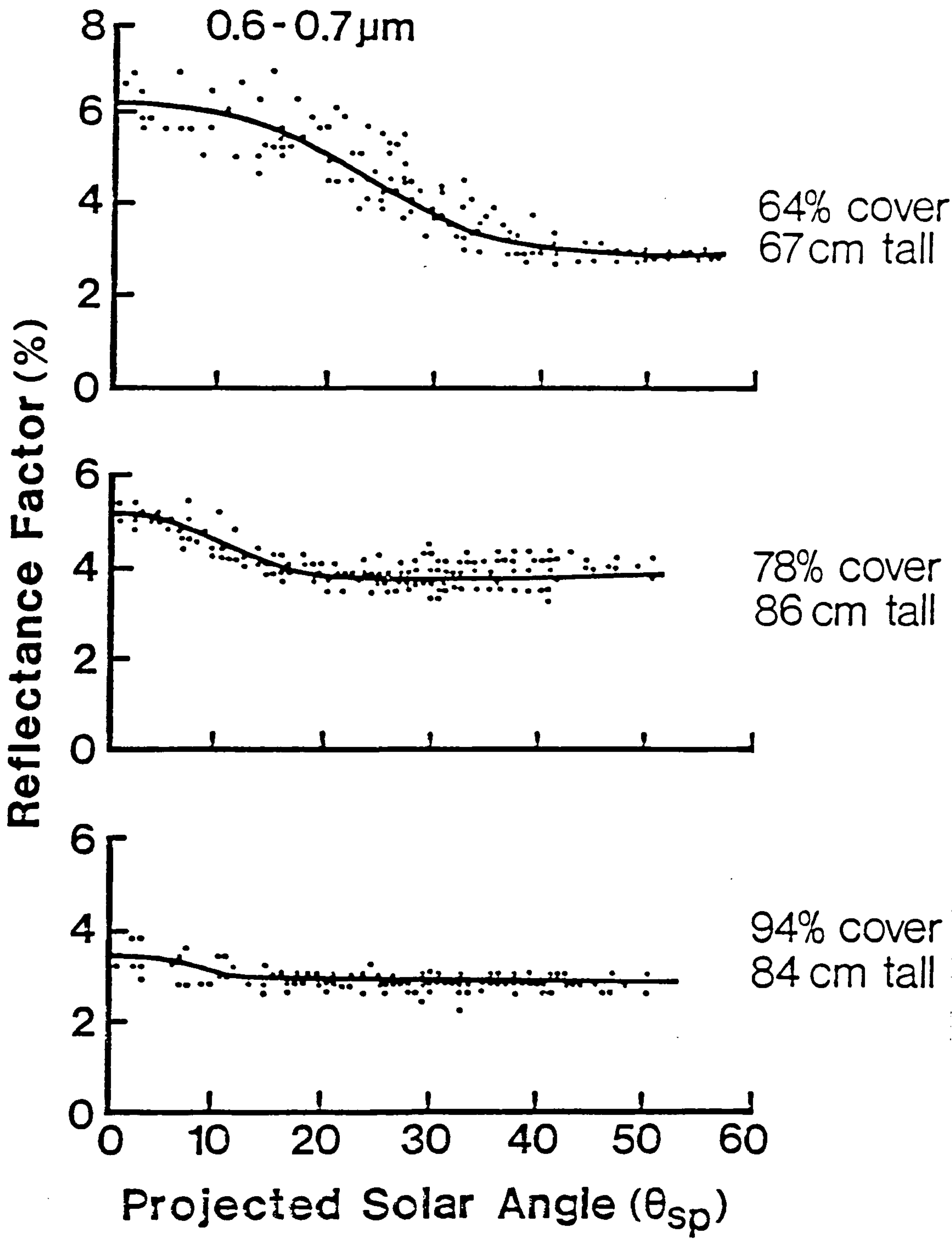
Reflectance has also been found to be dependent not only on the row direction but also on the time of the day. Kollenkark *et al* (1981a) have found that the highest reflectance values were obtained when the sun was shining down the rows lighting the soil surface and thus giving high reflectance values, and the lowest was recorded when the soil was shaded. The effect of sun-row azimuth interactions is illustrated in figure 3.15 (Kollenkark, *et al* 1981a).

There is a relationship between Leaf Area Index (LAI) and the reflectance factor of the vegetation canopies in all spectral bands. It is important to study this relationship under different sun and view angles. Ranson *et al* (1985) studied the effects of this relationship for corn canopies at different stages of development. They found that for nadir-view angles there was a strong effect of solar zenith angle on reflectance in all spectral bands for canopies with low LAI, and with high LAI, the effect of sun angle was small. They further concluded that, for canopies with low LAI, as view zenith angle increased, reflectance decreased for both visible and short wave infrared bands, while for higher LAI reflectance factor in the same bands increased as view zenith angle increased (Ranson *et al* 1985). This shows the significance of sun-view angle effects on the reflectance of vegetation canopies.

To study the effects of row direction, row width, and solar azimuth and zenith angles, Kollenkark *et al* (1981a) measured reflectance for soybeans over 11 plots with different row directions. They obtained three measurement dates over three development stages with 65, 78, and 94 percent soil cover for most of the plots used in the study. They concluded that when the reflectance factor was measured at nadir over all the plots, the effect between 20 and 60 degrees of solar angles was found to be non-significant as illustrated in figure 3.16. The results indicated that the near infrared reflectance factor and greenness function were not as sensitive to changes in solar illumination angle in the row crop canopy observed as the visible region and near infrared/red reflectance ratio. The study further concluded that changes in the canopy shadowing may be a significant factor, particularly in the visible wavelength region, influencing the spectral reflectance of crop canopies (Kollenkark *et al* 1981b). This illustrates that the row direction, row width and solar azimuth have a significant influence on the reflectance factor of the vegetation canopy.

Wind is another important environmental factor which affects the spectral reflectance characteristics of the crop canopy. This factor must be studied if the remotely sensed data are to be used effectively. The effects of winds on the canopy geometry is represented by its influence on the orientation of plant parts. This effect varies with the wind speed, vegetation configuration, and wavelength of the spectral band used in the reflectance measurement. Strong winds can affect the estimation of the crop canopy parameters.This influence largely depends on the spectral band used in the reflectance measurements.

Figure 3.16
The relationship between the reflectance factor in the red wavelength (0.60-0.70μ m) and projected solar angle Θsp)
for three different canopies



Source: Kollenkark *et al* (1981a)

3.5.5. SELECTION OF SPECTRAL BANDS

The optimal choice of bands from the six or seven (including the thermal channel) TM bands have been studied by several researchers (Jackson *et al* 1983 ; Townshend *et al* 1983 ; Atkinson *et al* 1985). For agricultural land, Townshend *et al* (1983) highlighted TM bands 1, 3, 4, and 5 as the best bands for discriminating the agricultural land around New Madrid. These particular bands were selected because of the high inter-correlation between bands 1 and 2 and between bands 5 and 7 in the test scene.

Jackson *et al* (1983) studied the use of TM bands for agriculture and woodlands for two subscenes of Arkansas in US. A high correlation was found between the visible bands (band 1 and 2) and between the short wave infrared bands (band 5 and 7). As is clear from table 3.4 for both subscenes, there was strong correlation among the three visible bands (Jackson *et al* 1983). These correlations in all cases have exceeded 0.9. The table also illustrates the high correlation between band 5 and band 7.

In the UK, Atkinson *et al* (1985) used six TM bands for discriminating different land use classes in the Reading area. For all classes they found that bands 2, 3, 4, and 5 were the best four bands for separating all classes (Atkinson et al 1985). As is shown in table 3.6 TM bands 2 and 4 provide the most discriminating information for agricultural classes. Clearly, there are a number of differences between the various analyses. From the difference TM scenes studies an overall trend emerges, namely the importance of the near infrared TM band 4 (0.79 - 0.90μm), and secondly the importance of at least one band from the short wave infrared (TM5 or TM7) and at least one from visible wavelength (TM2 or TM3) (Townshend *et al* 1988).

Table 3.4

Correlation Matrices For Landsat-TM 4

For Arkansas U.S.

Correlation Matrices for Subscene 1.

Band	1	2	3	4	5	7
1	1.00					
2	0.967	1.00				
3	0.953	0.957	1.00			
4	-0.512	-0.473	-0.631	1.00		
5	-0.136	0.067	-0.245	0.713	1.00	
7	0.244	0.310	0.166	0.362	0.883	1.00

Correlation Matrices For Subscene 2.

Band	1	2	3	4	5	7
1	1.00					
2	0.950	1.00				
3	0.935	0.904	1.00			
4	-0.148	-0.029	-0.166	1.00		
5	-0.089	0.207	0.088	0.849	1.00	
7	0.253	0.431	0.361	0.592	0.904	1.00

Source: Jackson *et al* 1983.

Table 3.5

Divergence between classes in New Madrid Subscene

Class	Best Four Bands For Discrimination					
	1	2	3	4	5	7	6
Water			X	X	X	X	
Agric. Land	X		X	X	X		
Woodland	X		X	X	X		
Urban			X	X	X		X
Plume			X	X	X		X
Industry			X		X	X	X
All Classes			X	X	X		X

Source: Atkinson *et al* 1985.

Table 3.6

The best TM bands for discrimination between different classes in Reading subscene

Class	Best 2 Bands For Discrimination						Best 3 Bands For Discrimination						Best 4 Bands For Discrimination						Best 5 Bands For Discrimination					
	1	2	3	4	5	7	1	2	3	4	5	7	1	2	3	4	5	7	1	2	3	4	5	7
Agriculture		X		X				X		X	X			X	X	X	X		X	X	X	X	X	
Suburban				X	X			X		X	X		X	X		X	X			X	X	X	X	X
Woodland				X	X				X	X	X			X	X	X	X			X	X	X	X	X
Water				X	X			X		X	X			X	X	X	X			X	X	X	X	X
Central Business District				X	X					X	X	X		X	X	X	X			X	X	X	X	X
Total				X	X			X		X	X			X	X	X	X		X	X	X	X	X	

Source :- Atikenson *et al*, 1985.

This study used TM bands 2, 3, 4, and 5. The selection of TM2 (0.52 - 0.60 μm) as the representative visible band has the advantage that this band usually displays the largest dynamic range of the three visible bands. The second reason for selecting TM2 rather than TM1 is the high correlation of 0.971 between these bands. The correlation matrix for a subscene of the study area is illustrated in table 3.7. The table shows the high correlation between TM1 and TM2 indicating that TM1 could be omitted without serious loss of information. For bands TM5 and TM7, the same situation is observed, given the high correlation between them. TM band 5 was used also because of its high sensitivity to leaf moisture.

Table 3.7

Correlation Matrices For Landsat-5 TM

Subscene of the Study Area.

Band	1	2	3	4	5	7
1	1.00					
2	0.971	1.00				
3	0.946	0.949	1.00			
4	-0.489	-0.451	-0.420	1.00		
5	-0.224	0.101	-0.275	0.608	1.00	
7	0.244	0.298	0.179	0.382	0.897	1.00

In summary, only TM bands 2, 3, 4, and 5 were used in the study despite the availability of all seven bands, for the following reasons.

i. Band 1 is most affected by the atmospheric conditions. (see Figure 3.6).

ii. The thermal band TM6 was not used because of its coarse spatial resolution.

iii. The high correlation between band TM1 and TM2 and between TM5 and TM7.

iv. These bands have been selected because the large quantities of data and time needed to analyse all the seven TM bands.

v. The cost associated with the purchase and analysis of all TM seven bands is significantly higher than a chosen subset of only four bands.

vi. Previous studies have shown that TM bands 2, 3, 4 and 5 have shown to be significant for giving good separability between agricultural classes (Jackson *et al* 1983; Atkinson *et al* 1985 ; Townshend *et al* 1988).

CHAPTER 4

ESTIMATING CROP AREA USING FIELD DATA

4.1. INTRODUCTION

This chapter outlines the sampling strategy and the statistical methodology of the field survey which was designed to obtain estimates of crop type areas for County Durham. Before describing the overall methodology of the sampling strategy developed in this study, it is important to give a brief background on sampling and its advantages.

Why Sampling ?

The main purpose of any sampling procedure is to choose a subset of data values which will reproduce the characteristics of the population as closely as possible. Sampling rather than total enumeration can be justified on several grounds. The following are the main reasons for sampling.

i. If data are required only at a high level of generalisation, e.g. for the country as a whole or for individual counties, there will be advantages in respect of cost effectiveness in collecting only sample data. This will reduce costs and improve the accuracy by permitting scarce resources of skilled manpower to be used to better advantage. For example, in County Durham the agricultural data are collected by postal questionnaire sent to each farmer in the County. This increases the cost associated with data collection by employing more skilled labour and spending more time on feeding these data into the computers. Time and cost could be reduced by using sampling surveys to collect agricultural statistics for County Durham.

ii. By sampling, data can be collected more quickly than through a total enumeration. This is because only limited areas will be surveyed fully. For instance, in this study only 44 km^2 were surveyed out of the 1415 km^2 of agricultural land in the

County.

iii. The surveys which rely on sampling have greater scope and flexibility in the type of information that can be obtained. This is because sampling concentrates on fewer individuals and, therefore, allows more comprehensive data to be collected. For example, the questionnaire used in this study allowed detailed questions to be asked and more information to be recorded by visiting each sample unit in the study area.

iv. Also, sampling can obtain information about a population which is impossible to collect in full, such as in the case of soil and geological studies.

4.2. THE SAMPLE DESIGN

The sampling approach implemented for this study was designed to provide a data base which may be used statistically in different ways (Latham *et al* 1981). The information obtained from the field survey will be manipulated in order to produce three crop type area estimates.

i. The first estimate is based on stratified random sample.

ii. The second estimate was derived from the classification of a Landsat-TM image of the study area.

iii. The final estimate is obtained by combining the above two estimates by applying a hybrid approach.

This chapter describes the sample design and outlines the statistical methodology developed to obtain an estimate of the area of each crop based upon a stratified random sample. The methodology of using field data by applying a stratified random sampling approach for crop type area estimation is illustrated in figure 4.1. The methodological approach for classifying the Landsat-TM data and the tabulation of these results will be discussed in chapter five. Chapter six will describe in detail how the information obtained by the field survey was utilized in conjunction with Landsat TM data in order to imrove the estimation procedure.

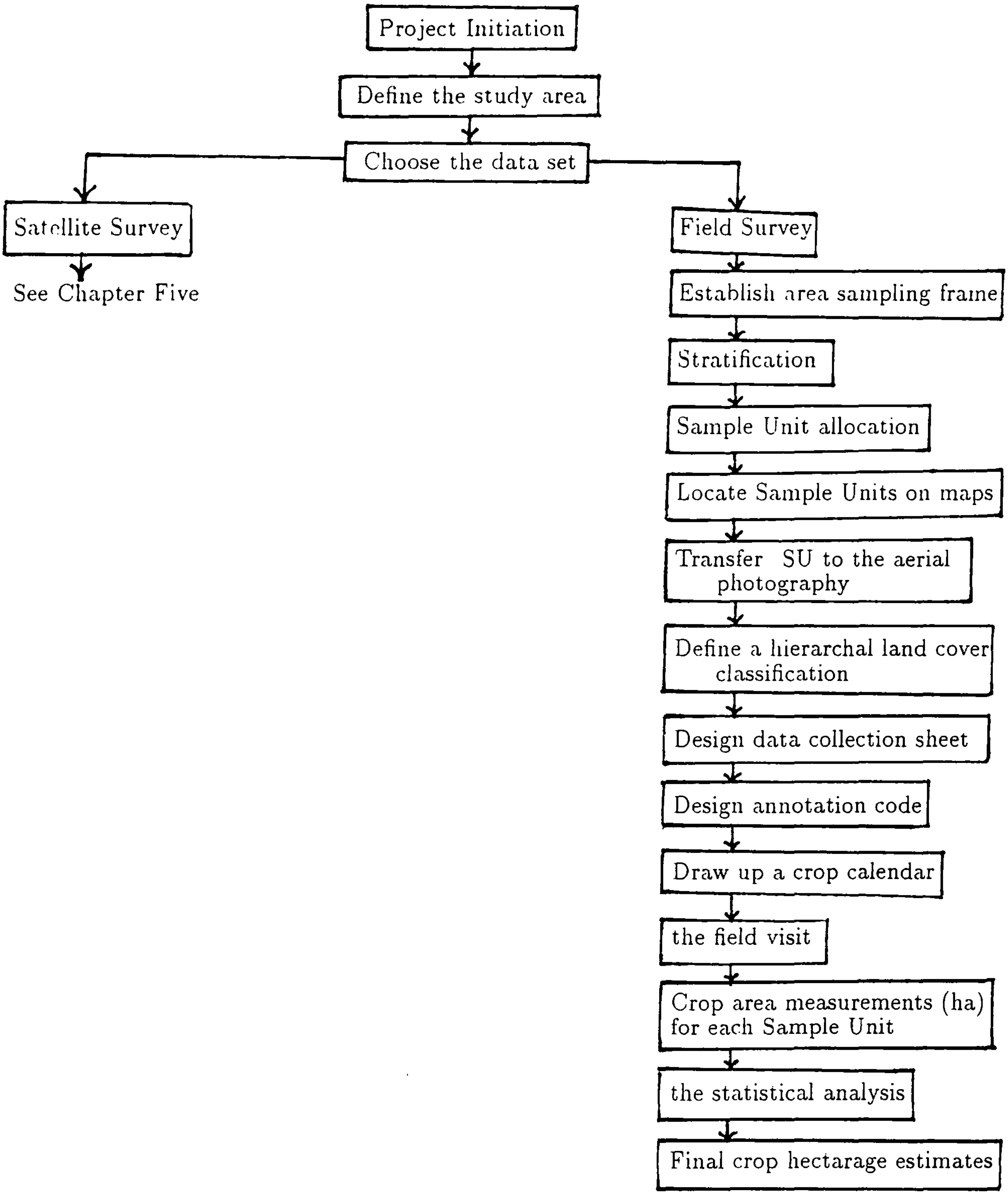
4.3. SAMPLING FRAME

A land use classification system was designed to suit the study area (see section 4.6.2). In this study, the moorlands and urban areas were excluded from the main sampling frame. The sampling frame includes only the agricultural land.

To determine the sampling frame, a 1:50,000 Landsat TM Enhanced False Colour Composite (EFCC) print of the study area was used (see chapter 3). The 1:50,000 OS maps were overlain over the 1:50,000 EFCC print and the sampling frame was marked on the OS maps. This procedure was carried out to determine the areas to be included in the frame. The main reason for using the EFCC print of the study area, is that it shows sharp contrasts between different land-cover classes such as moorlands, urban and agricultural land.

Figure 4.1

The Methodology of Applying a Stratified Random Sampling Approach for Crop Type Hectarage Estimates



4.4. SAMPLE UNIT SIZE

In order to apply any sampling technique, the population must be subdivided into smaller units called sampling units which form the basis for the selection of the sample. These SU's together comprise the whole of the population. Every element of the population must belong to only one SU. In remote sensing studies the following considerations must taken into account before determining the size of sample units.

i. The objectives of the survey.

ii. The spatial resolution of the sensor being used.

iii. The original size of the population from which the samples are to be chosen.

iv. The different characteristics of the individual units within the population.

v. The degree of accuracy required, and

vi. The availability of financial resources.

The two most important factors which determined the sample unit size in this study were the average field size within the study area and the spatial resolution (IFOV) of the satellite sensor used. The SU size could not be smaller in area than the size of the pixel. According to the above criteria, a pilot study was carried to find out whether 0.25, 0.50 or 1.0 km^2 was the best size. From that survey it was decided that 1.0 km^2 was an appropriate size for the SU's allowing for the factors mentioned above.

Also, the size of individual SUs should in part be determined by the ease with which they can be located on the Landsat image. Because it was desired to have the SU's equal in size, the grid square of the 1:50,000 OS maps was used which was equal to 1 km^2. So the SU size equalled 100 hectares (ha) which is equivalent to the area of approximately 33 picture elements (pixels) on the Landsat TM image.

4.5. METHODS OF SAMPLE SELECTION

To describe the method by which the sample has been selected for this study , it is important to illustrate other methods and to show their limitations. This section describes commonly used methods for sample selection and the next section describes the method used in this study.

Once it is decided what data is to be collected, and the sample size has determined, it is important to choose which method of selection is to be employed. Methods for selecting the sample units from the sampling frame include :-

- simple random sampling
- systematic sampling
- stratified sampling

4.5.1 Simple Random Sampling

The most commonly used method of sampling is probably a simple random sample. Selection should be carried out so that every individual element within the sampling frame has an equal opportunity of being chosen. The elements in the sample frame are numbered from 1 to N and the sample selected randomly.

Each individual element of the population must has an equal probability to be included in the sample, and the sample unit selection should be independent of each other. In other words, a random sampling approach should meet two important criteria. Random sampling must ensure independence of selection. This means that units selected should not influence the selection of any other units. Secondly, every individual in the population must have an equal probability of selection. Since each unit is selected with equal probability, the method is called simple random sampling without replacement. That means each individual unit which has been drawn is removed from the population for all subsequent draws. While in the case of sampling with replacement, the unit which has been selected is replaced and has a chance of being selected again. However, we would expect that ruling out the possibility of multiple occurrence of population members in the sample must potentially lead to greater efficiency of estimation.

4.5.2. Systematic Sampling

A systematic approach has significant differences from simple random sampling despite the fact that both methods may adopt a random approach. Operationally, systematic sampling is the simplest sampling procedure to use. Once an initial sampling unit is selected (which may be done randomly) from the frame, then all subsequent sample units are chosen in a regular sequence starting with the initial unit. For example, to select a one in k sample from a list of units is to select first a random number between 1 and k and then select the unit with this serial number and every kth unit afterwards (Hansen *et al* 1953, Som 1973). For instance, if k is 7 and the first unit drawn was number 11, then the subsequent numbers 18, 25, 32, and so on. Therefore, the selection of the first unit determines the whole sample.

The main advantages of systematic sampling are its ease of application and its flexibility to cover the whole population if the frame is ordered. Cochran (1977) argued that systematic sampling seems likely to be more precise than simple random sampling. The main reason cited was that systematic sampling stratifies the population into different parts which are similar to stratified sampling with only one unit per stratum (Cochran 1977). The inexpensive cost of this method makes it more popular than others.

Despite all of these advantages, the systematic sampling approach does not produce independent selection such as is the case in the simple random case because once the initial unit has been chosen, all other selections follow. This however limits the use of the resulting data. Also, if the sampling frame of the population has not been arranged in a good order, the systematic sampling could produce inefficient samples (Som 1973).

4.5.3. Stratified Sampling

As mentioned in the previous section, despite its wide use, simple random sampling has the limitation that subsets of the population may not get adequate coverage. To overcome some of these disadvantages, a stratification procedure was applied.

Here, the sampling frame is divided into small groups called strata and the simple random sampling procedure is carried out independently within each stratum. Such a stratified random sample offers a method of overcoming the imprecision of simple random sampling. This process is normally undertaken prior to sample selection. Therefore, the stratification process may be undertaken after the selection of sampling units. The main reasons for stratification are:-

i. When the data are more homogeneous within each stratum than in the population as a whole, reduced variability within each stratum will produce stratified sampling estimators which have smaller variance than the estimators produced by simple random sampling from the same sample size. Stratified sampling process requires a smaller sample size which in turn reduces the cost of the sampling. Therefore, stratification could be adopted in a situation where estimates of population characteristics are required with increased efficiency per unit of cost.

ii. The stratum has fewer sample units and may cover a smaller geographic area. Therefore, it is easier to choose the samples and collect the data from the smaller strata. With fewer sample units and smaller geographic areas the field work will be easier to organize in the different strata. This will ensure a good coverage of the population.

In summary, stratification has two main purposes, the first is to increase the accuracy of the overall population estimates. The second important objective is to ensure that subdivisions of the population which are themselves of interest are adequately represented (Yates 1949). For efficient stratification, strata should be so formed as to be internally homogeneous with respect to the within stratum variance.

As has been mentioned earlier, each stratum contains fewer sample units than the sampling frame as a whole, which may or may not be the same number in each stratum (Latham *et al* 1982). This depends on:-

i. The proportional allocation to strata size.

ii. Allocation to strata where the perceived density of the phenomena of interest is greatest.

There are many bases for stratification. These depend on the purpose of the survey and the nature of the phenomena to be studied. For example, in the agricultural application of remote sensing, the following criteria could be considered as a basis for stratification :-

- Type of farming.
- Field size.
- Type of land use.
- Agricultural intensity.
- Soil types.
- The topographic characteristics.
- Administrative boundaries.
- The environmental considerations.
- Geological formation of the area to be studied.

4.6. THE APPLIED APPROACH

The method to be used to generate the geographical location of the sample units had to be chosen with care. A simple random sampling method was excluded as this may give a low level of precision (Cochran 1977). Also, despite its wide use there is the possibility that using simple random sampling some subsets of the population may not get adequate coverage. To overcome some of these disadvantages, a stratification procedure was applied to the study area by combining the simple random and stratified sampling approaches. The sampling frame was divided into five main strata (see figure 4.2).

Given the nature of the study area, the following basis were used in this investigation as the main criteria for the stratification :-

i. agricultural intensity,

ii. field size,

iii. type of farming ,

iv. soil types,

v. the topographic nature of the area,

vi. type of land-use.

Given the the nature of the study area, the six factors described above were used in this investigation as the main criteria for the stratification and believed to be appropriate to the environment within which one wishes to establish a double sample relationship (Allan *et al* 1982)

As was mentioned in chapter 2, county Durham is characterized by an increase in the proportion of arable crops moving from the west to the east of the County (see figure 4.2). Stratification according to agricultural intensity was an important criterion due to the substantial differences in agricultural pattern between east and west of the County. The type of the farming pursued in the west of the study area dominated by rough grazing which diminishes as one goes towards the east where an increasing acreage is devoted to cereals and arable crops (see chapter 2).

In this study, differences in field sizes were viewed as an important stratification criterion. The field size increases from the west to the east of the county. Therefore, the selection criteria are interrelated which reinforces the choice of these criteria as the basis for stratification of the region.

Given the reasons for stratification mentioned in the previous section as well as the basis for the stratification mentioned above, the methodological approach followed in this study can be summarized in the following steps.

i. The sampling frame of the study area was subdivided into five main strata (see figure 4.2).

ii. The proportional size of each stratum was determined (see table 4.1).

iii. The number of the sampling units which had to be selected from the whole population was determined to be 3.1% for the five strata as a whole. This sample size was believed to give adequate precision (Cochran 1977). The sample size in each stratum was obtained according to its proportional size to the whole population, except in stratum four, where it was believed that five sample units were not adequate to implement the statistical methods described in chapter six.

iv. To select the sample units a simple random sampling approach without replacement was applied in each stratum separately. That means each individual unit which has been drawn is removed from the population for all subsequent draws. The simple random sampling has fulfilled two important criteria, the selection of the units was independent of each other. The second important criteria was that every individual unit in the population had an equal opportunity to be included in the sample.

Figure 4.2

The Main Strata of the Study Area

The stratification was implemented using 1:50,000 EFCC print (reduced for inclusion here)

4.7. FIELD DATA COLLECTION PROGRAMME

The field survey was conducted between May and September 1988. Forty four SU's were surveyed. Before an actual visit to the field to collect the information from each SU, it was necessary to :-

i. allocate the SU's,

ii. to develop a land use classification system which will be appropriate to the study area,

iii. to understand the agronomic nature of the crops being used in the investigation, and

iv. to design a data collection sheet (questionnaire) and the annotation key for recording the information collected.

4.7.1. SAMPLE UNITS ALLOCATION

Each sample unit was located in the field with the aid of 1:50,000 OS maps, air photography and Landsat-TM satellite imagery. As mentioned in section 4.3, a $1.0km^2$ grid was chosen to be the sample unit size for the purpose of this research. The OS 1:50,000 maps already have a $1.0km^2$ grid. Therefore, it was easy to plot the sampling frame. The area was stratified by overlaying the OS maps on the Landsat-TM imagery (geometrically corrected to National Grid) printed at 1:50,000 scale and selecting simple random sample for each stratum independently.

Stratified random sampling was undertaken on approximately 3.1% of the study area (see table 4.1) in order to select the areas on the ground to estimate the agricultural crops on a SU basis. The requisite number of units (n_h) were selected at random from the total units of each stratum (N_h), within which the variable of interest was measured (y_i). The number of the sample units (n_h) in the whole frame ranged from 7 to 11, and a total of 44 sample units were selected (equivalent to 3.1% of N_h).

Table 4.1

The Sample Allocation

Stratum no. (h)	Stratum area km^2	Stratum Proportion (100%)	Number of SU's N_h	SU allocation n_h
1	359	25.4	359	11
2	244	17.4	244	7
3	298	21	298	9
4	187	13.2	187	7
5	327	23	327	10
Total	1415	100		44

The method of sampling unit allocation begins with the calibration of sample unit to a map base, that is the exact location of a SU is translated into a set of latitudinal and longitudinal coordinates. Then each SU was transferred from the 1:50,000 OS maps to the aerial photography (AP). The AP was taken as a basis for the field survey. To check if there were any changes in the field boundaries, tracing paper was overlain on the AP, in order that any changes could be noted during the survey (see section 3.3). This method was applied because some boundaries of the fields inside the SU's had changed. Those changes could increase bias as a result of greater ambiguity about boundary locations (Latham *et al* 1982). Therefore, updating of boundaries was necessary and Latham (1982) emphasizes that this process will achieve improvements in sampling efficiency.

4.7.2. LAND USE AND LAND COVER CLASSIFICATION SYSTEM

Before developing a land use classification system to suit the study area, existing systems are first reviewed. At this stage it is important to distinguish between land-use and land-cover (Estes *et al* 1982). Land-use usually relates to man's activities on or relating to the landscape, while land-cover relates to the description of the features covering the land surface such as agricultural land, forestry and so forth.

There are many different systems for classifying land use. Each system has been developed according the needs of the users. Therefore, each system has been established according to different criteria. For example, (Anderson *et al* 1976 ; Rhind and Hudson 1980 ; Lo 1986) :-

i. Each item of classification must fall into one class only.

ii. It has to meet the needs of the primary as well as the secondary users.

iii. It must be easy to apply.

iv. Repeatable results should be obtainable from one interpreter to another and from one time to another.

v. The system must be adaptable to be used over large geographic areas.

vi. It has to be hierarchical, which could be useful in terms of the system's application at different levels of resolution.

vii. It should be suitable for use with different level of spatial resolutions.

viii. The system has to be flexible to use sub-categories. This can be obtained by using ground surveys or from the use of large scale aerial photography.

ix. The application of the available and rapidly expanding remote sensing technology, must be taken as a prime consideration in developing a framework of land-use and land-cover classification.

To develop a land-use classification system to be used with remote sensing techniques we must first determine the ability of different sensors to provide information for different levels of classification. The detail of information which can be obtained by a sensor depends on two important factors. First, is the characteristics of the sensor used. Secondly, the degree and accuracy of the information obtained, as well as processing methods required should be determined.

Spatial resolution is the most important factor among the characteristics of the sensor which influences the degree accuracy and detail of remotely sensed data. In Landsat satellites this resolution has been improved from 80 m for MSS to 30 m for TM (see section 3.5). Such an improvement in the spatial data resolution of the remote sensing satellites has increased the potential applications of these data for land-use and land-cover studies.

The methods of analysis of remote sensing data influence the accuracy and the degree of detail of the information which can be derived from these data. For example, using ground and map data to support satellite remote sensed data in land-use studies has been recommended by many researchers.

Most of land-use and land-cover classification systems have been designed in the USA or the U.K. Some of these systems are :-

- the World Land Use Survey (WLUS) Classification
- the Second Land Utilisation Survey (SLUS) Classification
- Department of the Environment (DoE) Developed Area Classification
- United States Geological Survey (USGS) Classification
- the National Land Use Classification (NLUC), and
- the National Gazetteer Pilot Study (NGPS).

Despite these many systems, only the USGS and DoE classification systems have been designed to collect data from remote sensed imagery. Particularly that of spatial resolution from I to IV as illustrated in table 4.2.

The USGS land-use and land-cover classification systems have been designed for use with remote sensed data from high altitude or space and were intended to meet the following criteria (Anderson *et al* 1976):-

i. a minimum level of interpretation accuracy of at least 85 per cent,

ii. equal accuracy for the interpretation of the different categories,

iii. repeatable results,

iv. the applicability over large areas,

Table 4.2

Land Use Classification Levels

Classification Level	Data Source	Map Output Scale
I	- Satellite images	1:25,000 - 1,000,000
II	- High altitude and & satellite imagery combined with topographic maps	1:80,000 and smaller
III	- Medium altitude remote sensing platforms combined with maps and substantial amount of supplemental information	1:20,000 to 1:800,000
IV	- Low altitude (below 3000m) remote sensing platforms with most of the information derived from supplemental sources	1:2,500 to 1:20,000
V	- Mainly ground surveys supplemented by maps (1:1000 or 1:10,000) derived from very low altitude remote sensing platforms (aerial photos)	1:100 to 1:10,000

Source: Anderson *et al* 1976 ; Rhind and Hudson 1980.

v. it should permit vegetation and other types of land-cover to be as surrogates for activity, and

vi. it should be possible to be used with remote sensed data acquired at different times.

The USGS has designed a classification system which contains four levels (Anderson *et al* 1976). To cope with the more detailed surveys recently carried out in U.K., Rhind and Hudson (1980) have modified the system to contain an extra level of classification. This is despite the fact that this added level of classification could not be obtained from the satellite or the high altitude remote sensed data.

Landsat MSS has produced good results when used for land cover classification studies, despite the fact that it has suffered from a number of first generation disadvantages (see chapter 3). Landsat TM however, was designed to overcome these difficulties. However, the main improvements were the higher spatial resolution and increase in the number of bands as well as the improvement in the radiometric resolution.

The study will test the capability of Landsat TM data for the identification of a more detailed level of land-use and land-cover classification system. Table 4.4 shows the system which will be examined in County Durham. It will contain only two categories (sub-classes): agricultural land and non-agricultural land. The latter sub-class will mainly include urban, highways, forest, waters, and so forth.

Table 4.3

Land Use Classification System For Use With Remote Sensed Data

1. Urban or Built-up Land	11. Residential 12. Commercial and Services 13. Industrial 14. Transportation, Communication and Utilities 15. Industrial and commercial Complexes 16. Mixed Urban or Build-up land 17. Other Urban or Build-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 Lands.
3. Rangeland	31. Herbaceous Rangeland. 32. Shrub and other Rangeland. 33. Mixed rangeland.
4. Forest Land	41. Deciduous Forest Land. 42. Evergreen Forest Land. 43. Mixed Forest Land.
5. Water	51. Rivers. 52. Streams and Canals. 53. Lakes. 54. Reservoirs. 55. Bays and Estuaries.
6. Perennial Snow or Ice	61. Perennial Snowfields. 62. Glaciers.
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. Wetland	91. Forest Wetland. 92. Nonforested wetland.

Sources: Anderson et al 1976.

TABLE 4.4 Land Cover Classification System used in the Study

- Agricultural land	11- Cropland and Pasture	111- Field Crops	1111- Wheat	11111- Winter Wheat
			1112- Barley	11121- Winter Barley
				11122- Spring Barley
			1113- Potatoes	
			1114- Oil Seed Rape	
		112- Agricultural Pastures	1121- Range land	
			1122- Weed	
			1123- Permanent Pasture	
	12- Tree Crops	121- Orchards		
		122- Groves		
		123- Bush Fruits		
		124- Horticultural Areas		
	13- Confined Feeding Operat's	131- Built-up Areas		
		132- Waste-disposal land		
	14- Other Agricultural Land	141- Agricultural Bare Soil		
		142- Agricultural Buildings		
		143- Others		
- Non Agricultural land	21- Forests			
	22- Urban			
	23- Water Bodies			
	24- High Ways			
	25- Quarry gravel and Sand			
	26- Moorlands			
	27- Others			

4.7.3. AGRONOMIC UNDERSTANDING

Agronomic understanding of the agricultural crops is crucial to the application of land-use classification and crop type area estimation using remote sensing data. It is important to determine the appropriate season for the agricultural areas to be sensed. Since different crops have different growth stages Landsat survey may be more accurately applied for some growth stages than others. Also, some agricultural crops may be confused with each other at certain stages of growth, because they may appear spectrally similar at the wavebands of the the TM sensor.

A crop calendar was constructed for the main arable crops in the County. This includes oilseed rape, winter barley, winter wheat, spring barley, spring wheat and potatoes. The information on the crop calendars were gathered from two main sources. The first, was the published and unpublished information on some of these crops (Harper and Berkenkamp 1975; Bland 1977; Lockhart and Wiseman 1983; ADAS 1984; Sylvester and Makepeace 1984). However, it was difficult to get a very precise detailed information on the crop calendar specifically for County Durham. Most of the information found was of a general nature such as calenders for cereals and not specifically for either wheat or barley. The second important source for information on crop cultivation was the discussion with the agricultural officers and farmers within the study area (MacDonald 1989; Jefferson 1988).

Winter wheat, winter barley and spring barley are the main cereal crops cultivated in in the county in large areas. Appendix B illustrates the growth stages of cereal crops in general. Both winter wheat and winter barley are planted and managed in much the same manner. The leaves of cereals differ in colour, those of wheat usually being a fairly dark green, those of barley a rather pale, almost yellowish green. In County Durham, winter barley and winter wheat crops are planted in October and harvested during August and September. The crops usually have the highest leaf area cover when they are in flag leaf stage (see Appendix B), which is generally between end of April and early May as shown in table 4.5. Spring barley has much shorter growing season than winter cereals (Bland 1977). The crop is sown in March and is harvested between September and October. The crop usually in its flag leaf stage at the end of June where it has its highest leaf area cover.

Oilseed rape is sown between mid August to mid September and harvested in late July. The growth stages of oilseed rape is illustrated in Appendix B. The crop is characterised by the distinguished yellow colour of its flowers. The flowering stage of oilseed rape starts usually between late May to early June (see table 3.4). The potato crop is planted in early May and have the highest leaf area cover normally at the end of July.

Table 4.5

The Crop Calendar for County Durham

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Winter Wheat				Fl	Fl			H	H B	S	S B	B
Winter Barley				Fl	Fl			H	H B	S	S B	B
Spring Barley				B S	B		Fl Fl		H H	B		
Spring Wheat				B S	B		Fl Fl		H H	B		
Oilseed Rape			Se	Se	Fr	Fr	H	H S	S B			
Potatoes					S B	B	T T					

Key

B	Bare soil	Se	Stem elongation stage
S	Sowing	Fr	Flowering stage
T	Tillering stage	H	Harvesting
Fl	Flag leaf stage		

4.7.4. FIELD DATA COLLECTION SHEET

Prior to the field visit, it was necessary to prepare appropriate forms and an annotation key as illustrated in figure 4.3. The questionnaire was designed in three main parts. The first section represents direct information about the physical characteristics of the sample units such as topographic shape of the area, the amount of natural vegetation, soil colour, and so on. Also recorded is the OS map sheet number containing the sample unit as well as the air photo number on which the SU is located. Also, any recent changes were recorded where it was believed significant alterations had taken place since 1971 when the air survey was carried. These changes include the new field boundaries or where farmers either build new hedges between fields or remove them to make two parcels into one big field.

This part of the questionnaire also recorded any other major changes such as deforestation, new forests, new buildings or new roads. The time taken to allocate the sample unit is also recorded in this part of the questionnaire together with the time of the inventory. After the classification of the Landsat data took place, any reasons for possible missclassification were described in this section of the questionnaire.

The second part of the questionnaire includes the annotation key for the land-cover classes of the study area (see section 4.7.2). The area of each land cover type was recorded after the measurements were made in the laboratory after completion of the survey.

The final part of the field data collection sheet represents the aerial photography and attached overlay to mark the field boundaries inside the sample unit. This makes it possible to write the name of each land-cover type as well as any changes on the overlay without obscuring the aerial photograph.

Figure 4.3

FIELD DATA COLLECTION SHEET

PART ONE

- Enumerator .... Date ....

- Strata ....

- Sample Unit No. ....

- Location Map Sheet No. ....

- Air Photo No. ....

- Time to locate the sample unit ....

- Average field size in the sample unit ....

- Topographic Characteristics (eg. slope) ....

- Soil colour ....

- % of natural vegetation ....

- Changes in field conditions between 1971 and 1985 (new roads, new field boundaries, new buildings, if any new forests or deforestation, etc.) ....

- No. of fields visited in the sample unit ....

- Time of inventory ....

- Possible reasons for any missclassification, if any ....

....

PART TWO

The annotation key for the land-cover classes in the study area

Land-cover class	Annotation key	Area in hectare (ha)
Winter Wheat	WW	
Spring Wheat	SW	
Winter Barley	WB	
Spring Barley	SB	
Oilseed Rape	OSR	
Pastures	P	
Forests	F	
Bare Soil	B	
Vegetables	V	
Fruit Trees	FT	
Fodder Crops	FO	
Market Garden	MG	
Moorlands	M	
Water	W	
Urban	U	
Highways, Roads, etc.	H	
Others	O	

PART THREE

Overlay represents the boundary of 1km² sampling unit near Spennymoor. The clearly illustrates the field boundaries. These fields were surveyed by the author.

Source :- B.K.S Surveys

4.7.5. FIELD VISIT

Once the sample units were allocated and the questionnaire was prepared, the field visit took place. The field work survey lasted approximately five months commencing in May 1988 and terminating in September of the same year. During this period, forty four 1 km^2 SU's were surveyed.

The inventory of a 100 hectares sample unit* at a field level was implemented in a period between three and five hours depending on how many farms were to be visited. Since the fields included in each sample unit belonged to more than one farm, it was sometimes necessary to interview more than ten farmers in the area to cover all fields in the sample unit. In some instances there are some fields in the sample unit which belong to farms a few miles away. For example, the author had to travel about 12 miles to get information about one field in the sample unit.

Also, the time of inventory depended on the availability of the farmers in their farms at the time of inventory. For instance, in one case the author had to return in few days time to interview a farmer. In other cases he had to come back more than once.

The interviews with farmers who keep records on their farms took less time than with those who do not keep records of their farms. In the latter case, the data are dependent on the farmers memory (without any recorded information) and so may not always be entirely accurate. If the farmer is practising a specific crop

* *1.0km^2= 100 hectares since 1.0 ha* $= 10^4 m^2$

rotation he will easily determine what was planted in his field in 1985. Fortunately, in the study area most of the farmers practice a crop rotation. The most common rotation in the region is wheat-wheat-barley-oilseed rape (see section 2.6).

4.8. STATISTICAL METHODOLOGY

The statistical procedures applied in this study as outlined by several authors including Snedecor and Cochran (1967) ; Cochran (1977) ; Yates (1981) who discussed the survey sampling techniques. The statistical methodology followed was developed according to the procedures used by the USDA (Hanuschak *et al* (1979) ; Cook *et al* (1984) ; and others), Latham *et al* (1982) in Gefara Plain, Libya, Hafner *et al* (1982) in Yemen, and by Angelis and Gizzi (1984) in Italy.

The statistical methodology for field data analysis was applied for each crop and stratum (h) separately, and finally the sample results were aggregated into one number.

Based on simple random sampling, it was desirable to calculate the average area (ha) $\bar{y}_h$ for each stratum, where

$$\bar{y}_h = \frac{\sum_{i=1}^{n} y_i}{n_h} \qquad 4.1$$

with estimated *variance* of

$$Var(\bar{y}_h) = (\frac{N_h - n_h}{N_h})(\frac{s_h^2}{n_h}) \qquad 4.2$$

where

$$\frac{(N_h - n_h)}{N_h} = \frac{1 - n_h}{N_h} = (1 - f) \qquad 4.3$$

where n_h is the number of the sample units in each stratum (h)

N_h is the potential sample size per stratum

$\bar{y}_h$ is the mean of the field area measurement (ha) in stratum h

and f is the sample fraction.

If the population size, N, is very large relative to the sample size, n, the $(1 - f)$ is essentially equal to one and the equation for $Var(\bar{y}_h)$ reduces to $\frac{s_h^2}{n_h}$. therefore

$$Var(\bar{y}_h) = \frac{s_h^2}{n_h} \qquad 4.4$$

If the sample size is equal to the population size, that is $N_h = n_h$, then $Var(\bar{y}_h) = 0$. This is because all units of the target population will have been included in the sample and observed which makes the sample mean equal to the population mean, that is

$$\bar{y}_h = \bar{Y}_h$$

To measure the amount of variance of the stratum population mean, it is important first to obtain the sample variance denoted by s_h^2.

$$s_h^2 = \frac{\Sigma(y_i - \bar{y})^2}{(n_h - 1)} \qquad 4.5$$

with *standard deviation*

$$s_h = \sqrt{\frac{\Sigma(y_i - \bar{y})^2}{(n_h - 1)}} \qquad 4.6$$

However, a large amount of variability in the sample is indicated by a large value of s^2 or s. In this context s_h is preferred to s_h^2 because the standard deviation is the measure of variability expressed in the same units of measurements (ha in this study) as the data value themselves. By using s_h^2 the results would be expressed in square values (ha^2).

The estimated *standard deviation* of the statistic is sometimes referred to as *standard error* in published articles (Denvore, J and Peck, R. 1986 ; Allen, J.D and Hanuschak, G.A 1988).

Standard error $(S.E)$ measures the variation of a mean value whereas *standard deviation* (s) and the *coefficient of variation* $(C.V)$ measures the degree of variation of individual values which contribute to the mean. Both *standard error* and *standard deviation* are in the units of the original measurements whereas the *variance* (s^2) from which they are calculated is in squared units. From equation 4.4, *standard error* (S.E) can be calculated as,

$$S.E(\bar{y}_h) = \sqrt{\frac{s_h^2}{n_h}}$$

which can be rewritten as

$$S.E(\bar{y}_h) = \frac{s_h}{\sqrt{n_h}} \qquad 4.7$$

The $S.E.$ of the estimate can be expressed as a percentage of the population value $(\bar{y})$. This form of expression is useful because the percentage *standard error* is unaffected by the units in which the estimate is expressed. Similarly, *the standard deviation* can be expressed as a percentage of the mean value. This is sometimes termed the *coefficient of variation.* Denoted by *C.V.*, the *coefficient of variation* expresses the *standard error* or *standard deviation* as a percent of the mean, it is defined by

$$C.V_h = \frac{\sqrt{Var(\bar{y}_h)N^2}}{N_h\bar{y}_h} \times 100 \qquad 4.8$$

$$C.V_h = \frac{N[SE(\bar{y}_h)]}{N\bar{y}_h} \times 100$$

$$C.V_h = \frac{SE(\bar{y}_h)}{\bar{y}_h} \times 100 \qquad 4.9$$

By using the formulas above, the stratum total is estimated as

$$\hat{y}_h = N_h \bar{y}_h \qquad 4.10$$

with a variance of

$$Var(\hat{y}_h) = N_h^2 Var(\bar{y}_h) \qquad 4.11$$

By using equation 4.4, it can be written as

$$Var(\hat{y}_h) = N_h^2 (\frac{s_h^2}{n_h}) \qquad 4.12$$

and the *standard error* of the mean as

$$SE(\hat{y}_h) = \sqrt{N_h^2 (\frac{s_h^2}{n_h})} \qquad 4.13$$

which is equal to

$$SE(\hat{y}_h) = N_h (\frac{s_h^2}{n_h})$$

From equation 4.7, this can be written as,

$$SE(\hat{y}_h) = N_h [SE(\bar{y}_h)] \qquad 4.14$$

The statistical procedures mentioned above were applied on a stratum (h) basis. All the results were aggregated over all five strata to yield an overall estimate of the population. The population mean was calculated from

$$\bar{Y} = \frac{1}{N} \sum_{h=1}^{5} N_h \bar{y}_h \qquad 4.15$$

with estimated variance

$$Var(\bar{Y}) = (\frac{1}{N})^2 \sum_{h=1}^{5} N_h^2 (\frac{s_h^2}{n_h}) \qquad 4.16$$

Also the *standard error* of the population mean was computed as

$$SE(\bar{Y}) = \frac{1}{N} \sqrt{\sum_{h=1}^{5} N_h^2 (\frac{s_h^2}{n_h})} \qquad 4.17$$

The estimated population aggregated over all strata, was obtained from the equation

$$\widehat{Y} = \sum_{h=1}^{5} N_h \bar{y}_h \qquad 4.18$$

with variance of

$$Var(\widehat{Y}) = \sum_{h=1}^{5} N_h^2 Var(\bar{y}_h) \qquad 4.19$$

The *standard error* of the estimated population is calculated as the square root of the $Var(\widehat{Y})$. Then

$$SE(\widehat{Y}) = \sqrt{\sum_{h=1}^{5} N_h^2 (\frac{s_h^2}{n_h})} \qquad 4.20$$

4.9. RESULTS AND DISCUSSION

Different land cover categories were measured in each of the sample units visited. The statistical methods mentioned in the previous section were applied for each stratum and the results were aggregated for all five strata to calculate the total crop type area estimates using stratified random sampling.

Tables 4.6 through 4.18 give detailed results of the application of the statistical methods of the above section. To obtain the sample variance for each stratum, it was necessary to compute the sample mean $\bar{y}_h$ and the sum of the squared deviation of $(y_i - y_h)$ in each stratum. This is illustrated in table 4.6.

Table 4.6

Sampling Results for Stratum 1 for Total Field Area Estimate of Oilseed Rape

Sampling Unit	Area (ha) (y_i)	Deviation $\Sigma(y_i - \bar{y})$	Squared Deviation $\Sigma(y_i - \bar{y})^2$
1	11.5	4.437	20.001
2	—	-7.0273	49.383
3	9.0	1.973	3.893
4	4.5	-2.527	6.386
5	20.5	13.473	181.522
6	5.0	-2.027	4.109
7	—	-7.0273	49.383
8	—	-7.0273	49.383
9	8.50	1.4727	2.169
10	18.3	11.2723	127.074
11	—	-7.0273	49.383
Sums	77.3		542.686

By using the statistical information outlined in table 4.6, the equations 4.5 and 4.6 were applied in order to calculate the sample variance (s_h^2) and standard deviation (s_h) of each stratum. These results are illustrated in tables 4.7, 4.8, 4.9, and 4.10.

Table 4.7

Total Field Area Estimate of Winter Wheat (ha)

Stratum	n_h	mean $\bar{y}_h$	$\sum(y_i - \bar{y}_h)^2$	variance s_h^2	st. deviation s_h
1	11	15.4182	1029.6361	102.9636	10.1471
2	7	11.5143	655.2084	109.2014	10.4501
3	9	7.7778	734.0552	91.7569	9.5790
4	7	2.9286	156.2142	26.0357	5.1025
5	10	0.5300	11.025	1.225	1.0680

Table 4.8

Total Field Area Estimate of Winter Barley (ha)

Stratum	n_h	mean $\bar{y}_h$	$\sum(y_i - \bar{y}_h)^2$	variance s_h^2	st. deviation s_h
1	11	12.2045	1166.102	116.6102	10.7986
2	7	14.5286	876.7344	146.1224	12.0881
3	9	14.0222	1331.136	166.3920	12.8993
4	7	2.5000	262.500	43.7500	6.6144
5	10	2.3000	476.100	52.9000	7.2732

Table 4.9

Total Field Area Estimate of Oil Seed Rape (ha)

Stratum	n_h	mean $\bar{y}_h$	$\sum(y_i - \bar{y}_h)^2$	variance s_h^2	st. deviation s_h
1	11	7.0273	542.6820	54.2682	7.3958
2	7	8.3571	605.8572	100.9762	10.0487
3	9	2.5000	200.0000	25.0000	5.0000
4	7	——	——	——-	——-
5	10	——	——	——-	——-

Table 4.10

Total Field Area Estimate of Pasture (ha)

Stratum	n_h	mean $\bar{y}_h$	$\sum(y_i - \bar{y}_h)^2$	variance s_h^2	st. deviation s_h
1	11	39.6591	1675.2840	167.5284	12.9433
2	7	35.9286	4174.2144	695.7024	26.3762
3	9	47.3333	2302.0000	287.7500	16.9632
4	7	77.2857	1057.4286	176.2381	13.2755
5	10	60.7800	6583.7583	731.5287	27.0468

Tables 4.11 through 4.14 outline the standard error of the mean and population in each stratum. The standard error of the stratum mean $SE(\bar{y}_h)$ and the standard error of the stratum population $SE(\widehat{y}_h)$ were obtained by using equations 4.7 and 4.12 respectively.

Table 4.11

Estimation of the S.E for Total Winter Wheat

Stratum	N_h	$S.E(\bar{y})$	$N[S.E(\bar{y}_h)]$	$N^2[S.E(\bar{y}_h)]^2$	$N_h\bar{y}_h$
1	359	3.059465	1098.34610	1206364.155	5535.1338
2	244	3.949710	963.72924	928774.0480	2809.4892
3	298	3.192995	951.51251	905376.0567	2317.7844
4	187	1.928571	360.64278	130063.2148	5476.6482
5	327	0.34999	1114.44673	13098.054 0	114.45
Sums			3488.67736	3183675.5285	16253.5026

Table 4.12

Estimation of the S.E for Total Winter Barley

Stratum	N_h	$S.E(\bar{y})$	$N[S.E(\bar{y}_h)]$	$N^2[S.E(\bar{y}_h)]^2$	$N_h\bar{y}_h$
1	359	3.2559	1168.8681	1366252.635	4381.4155
2	244	4.5689	1114.8116	1242804.903	3544.9784
3	298	4.2998	1281.3404	1641833.221	4178.6156
4	187	2.5000	467.5000	218556.250	467.5000
5	327	2.3001	752.1327	565703.5984	752.1000
Sums			4784.6528	5035150.6074	13324.6095

Table 4.13

Estimation of the S.E for Total Oilseed Rape

Stratum	N_h	$S.E(\bar{y})$	$N[S.E(\bar{y}_h)]$	$N^2[S.E(\bar{y}_h)]^2$	$N_h\bar{y}_h$
1	359	2.22114	797.38926	635829.6320	2522.801
2	244	3.79804	926.72176	858813.2205	2039.132
3	298	1.66667	496.66468	246675.8044	745.000
4	187	——	——	——	——
5	327	——	——	——	——
Sums			2220.7757	1741318.657	5306.933

Table 4.14

Estimation of the S.E for Total Pastures

Stratum	N_h	$S.E(\bar{y}_h)$	$N[S.E(\bar{y}_h)]$	$N^2[S.E(\bar{y}_h)]^2$	$N_h\bar{y}_h$
1	359	3.90254	1401.01186	1962834.232	14237.6169
2	244	9.96926	2432.49944	5917053.526	8766.5784
3	298	5.65440	1685.0112	2839262.744	14105.3234
4	187	5.01766	938.30242	880411.4314	14452.4259
5	327	8.55295	2796.81465	7822172.186	19875.0600
Sums			9253.63957	19421734.1194	71437.0046

The coefficient of variation (CV) for each crop type per stratum was obtained by applying equation 4.9. Table 4.15 shows the CV for each crop in all five strata. As it is clear from the table the CV is very high for winter wheat in stratum five. It is also noticed that, in strata 4 and 5 the CV scored the highest value, 100%. In fact the SE of the estimate is equal the estimate itself. The main reason for this high level of imprecision is that both stratum 4 and 5 have only one sample unit which contains that particular crop. For example, in stratum 5, only one SU has winter wheat, and in stratum 4, winter barley existed only in one sample unit. This caused the mean $\bar{y}_h$ to equal the $SE(\bar{y}_h)$.

The final area estimate for each crop using the field survey is shown under tables 4.15 to 4.18. The standard error of the population was computed by using equation 4.20. Using a 95% confidence limit, the total field area estimation of each crop was obtained by applying the equation

$$\widehat{Y}_{pop} = N_h \bar{y}_h \pm 2S.E(\widehat{Y}) \qquad 4.18$$

Figure 4.4 illustrates the final crop type hectarage estimates for all strata in the study area.

Table 4.15
Field Area Estimate (ha) for Winter Wheat
in County Durham, May 1985

Stratum h	Estimate (ha)	Standard Error $SE(\widehat{y}_h)$	Coefficient of Variation $C.V$ (100%)
1	5535.1	1098.3	19.8
2	2809.5	963.7	34.3
3	2317.8	951.5	41.1
4	5476.6	360.6	6.6
5	114.5	114.5	100

$$S.E(\widehat{Y}) = \sqrt{\sum_{h=1}^{5} N^2[S.E(\bar{y}_h)]^2}$$

$$\widehat{Y}_{pop} = N_h \bar{y}_h \pm 2S.E(\widehat{Y})$$

$$\widehat{Y}_{pop} = 16253.51 \pm 3568.57$$

Table 4.16

Field Area Estimate (ha) for Oilseed Rape in County Durham, May 1985

Stratum h	Estimate (ha)	Standard Error $SE(\bar{y}_h)$	Coefficient of Variation $C.V$ (100%)
1	2522.8	797.4	31.6
2	2039.1	926.7	45.5
3	745.0	496.7	66.7
4	——	——	——
5	——	——	——

$$S.E(\hat{Y}) = \sqrt{\sum_{h=1}^{5} N^2[S.E(\bar{y}_h)]^2}$$

$$\hat{Y}_{pop} = N_h\bar{y}_h \pm 2S.E(\hat{Y})$$

$$\hat{Y}_{pop} = 5306.93 \pm 2639.18$$

Table 4.17

Field Area Estimate (ha) for Winter Barley in County Durham, May 1985

Stratum h	Estimate (ha)	Standard Error $SE(\bar{y}_h)$	Coefficient of Variation $C.V$ (100%)
1	4381.4	1168.9	26.7
2	3545.0	1114.8	31.4
3	4178.6	1281.3	37.8
4	467.5	467.5	100
5	752.1	752.1	100

$$S.E(\hat{Y}) = \sqrt{\sum_{h=1}^{5} N^2[S.E(\bar{y}_h)]^2}$$

$$\hat{Y}_{pop} = N_h\bar{y}_h \pm 2S.E(\hat{Y})$$

$$\hat{Y}_{pop} = 13324.61 \pm 4487.83$$

Table 4.18

Field Area Estimate (ha) for Pasture in County Durham, May 1985

Stratum h	Estimate (ha)	Standard Error $SE(\hat{\bar{y}}_h)$	Coefficient of Variation $C.V$ (100%)
1	14237.6	1401.0	9.8
2	8766.6	2432.5	27.7
3	14105.3	1685.0	11.9
4	14452.4	938.3	6.5
5	19875.0	2796.8	14.1

$$S.E(\hat{Y}) = \sqrt{\sum_{h=1}^{5} N^2[S.E(\bar{y}_h)]^2}$$

$$\hat{Y}_{pop} = N_h\bar{y}_h \pm 2S.E(\hat{Y})$$

$$\hat{Y}_{pop} = 71437.00 \pm 8814.02$$

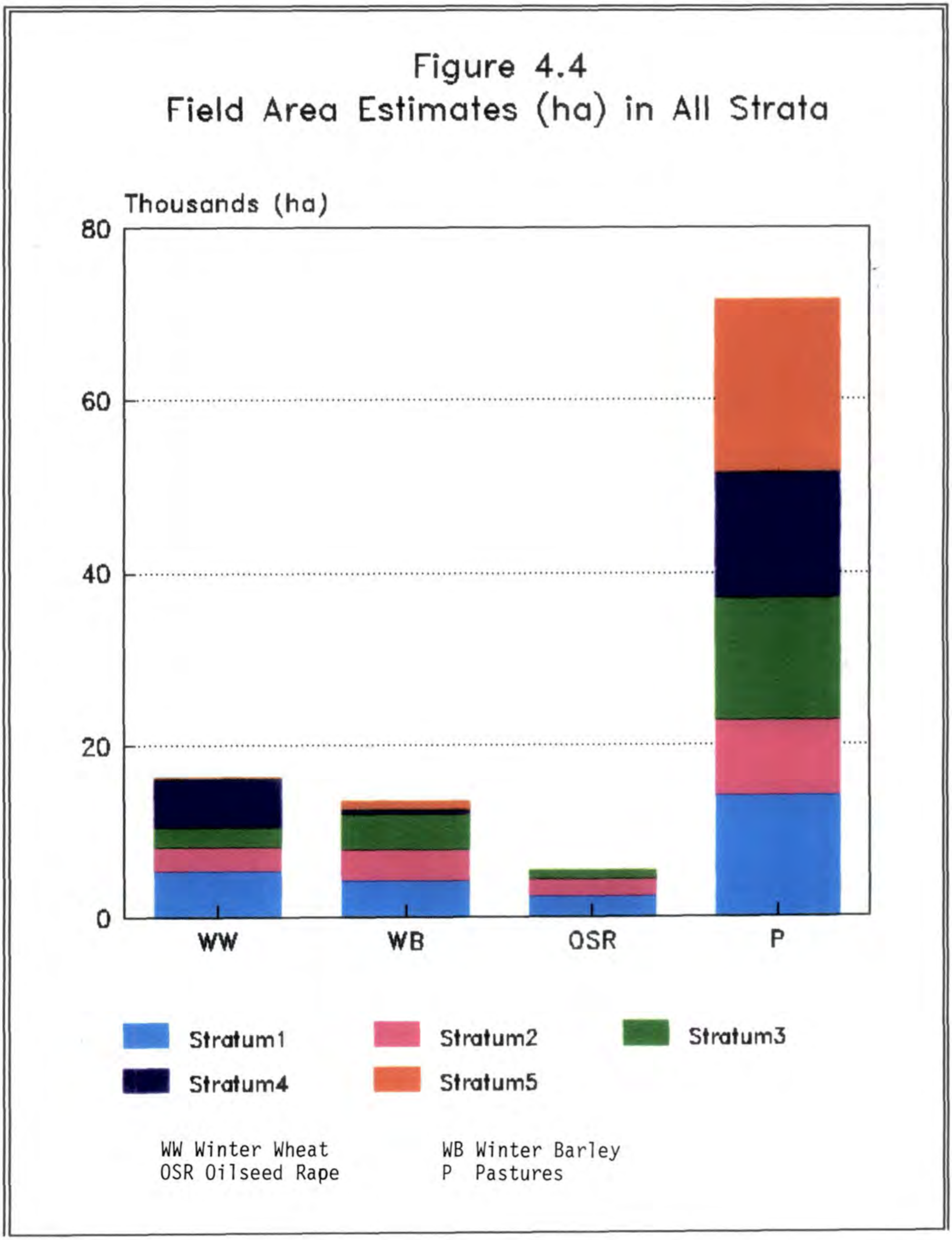


Figure 4.4
Field Area Estimates (ha) in All Strata
Thousands (ha)
80
60
40
20
0
WW
WB
OSR
P
Stratum1
Stratum2
Stratum3
Stratum4
Stratum5
WW Winter Wheat
WB Winter Barley
OSR Oilseed Rape
P Pastures

Chapter 5

CROP TYPE AREA ESTIMATION USING LANDSAT TM DATA

5.1. ADOPTED METHODOLOGY

This chapter describes the methods used to obtain estimates of crop area and land use in County Durham using Landsat-TM data. Figure 5.1 summarises the stages of the analysis which include:-

- pre-classification data processing
- data classification
- post-classification data processing.

The Landsat data are used in conjunction with field survey information to allocate each of the pixel elements to one of the land cover classification categories described in chapter four.

5.2. PRE-CLASSIFICATION DATA PROCESSING

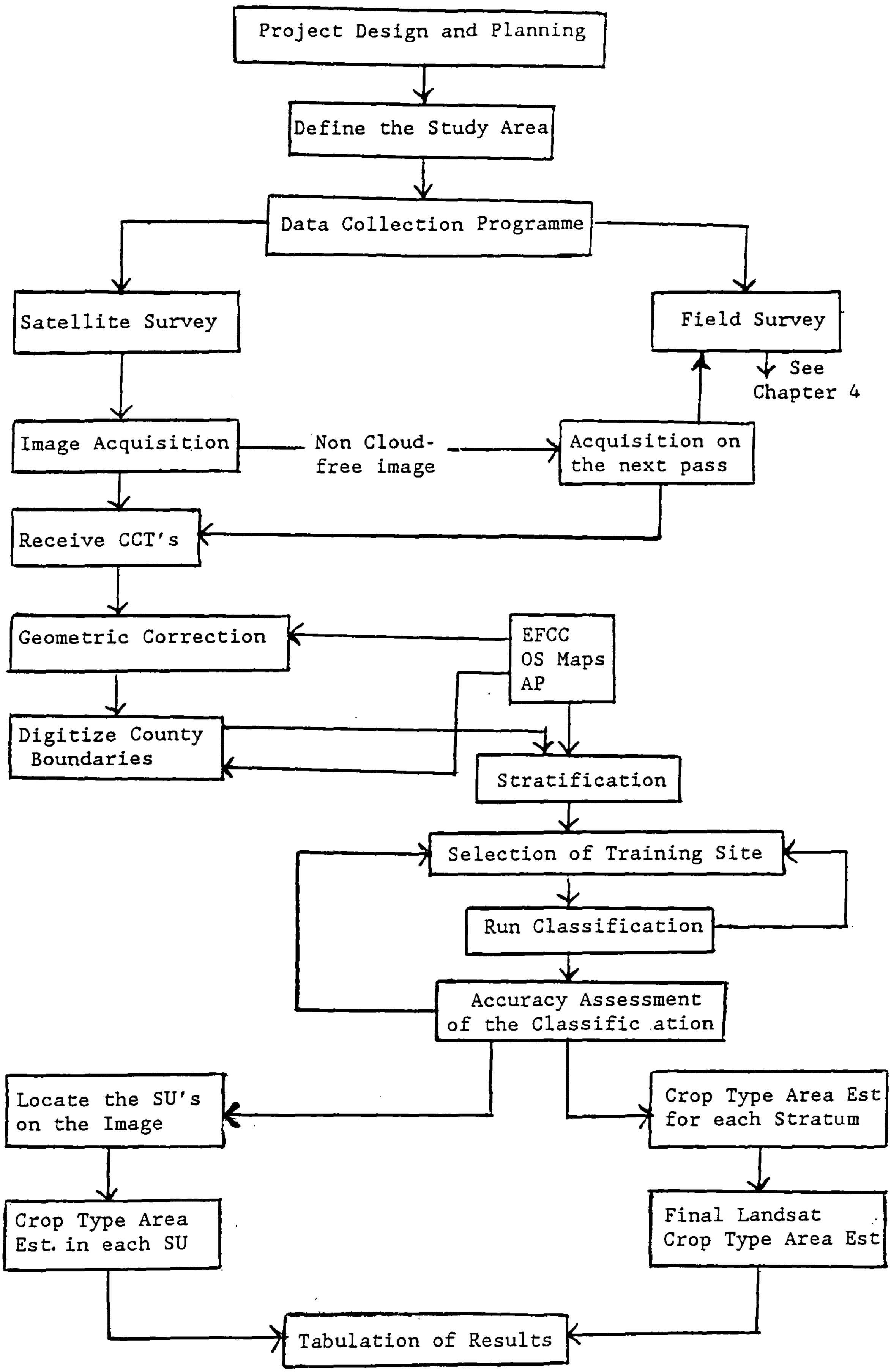
This process includes all the techniques applied to the Landsat-TM data before the classification process took place. In their article in 1969, Kriegler *et al* have defined the image pre-processing as

> *"in intermediate data transformation which is applied between the collection of data and the actual recognition operations."*

This process may affect the classification process. Therefore, the choice of pre-classification techniques is extremely important in this context.

In this study, the following three processes were applied to the four spectral channels of the Landsat-TM data (TM2, TM3, TM4 and TM5) before the data were classified. These were:-

1. Geometric Correction
2. Digitization of County Boundaries
3. Image Stratification.



(Figure 5.1)

Methodology flowchart for estimating crop type area using Landsat TM data.

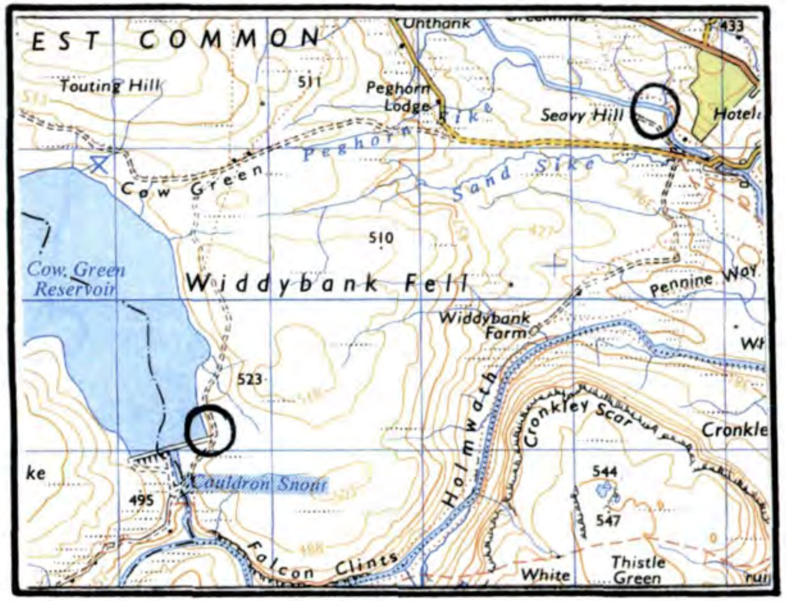
5.2.1. Geometric Correction

Images obtained from Landsat series satellites are not provided in a recognised map projection (Benny 1983). These data contain residual distortion due to earth curvture and satellite attitude as well as orbital variation (Gordon 1981). These variables include the tilt of the Landsat orbit with respect to the axis of the earth, the rotation of the earth under the satellite and the non-spherical shape of the earth.

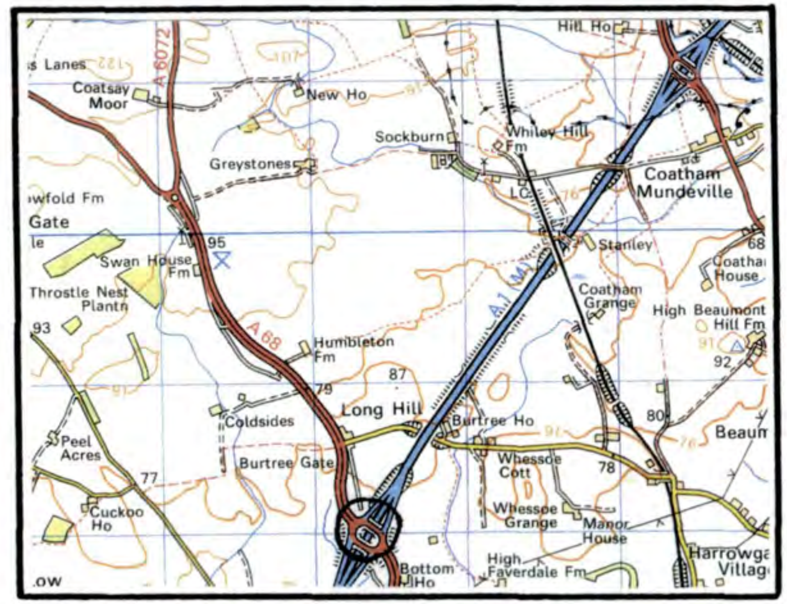
These distortions necessitate changes in the geometrical properties of the Landsat image to correct for systematic pixel positional errors or to perform image-to-image or image-to map registration (Schowengerdt 1984). The objective of geometric correction may be to place TM image samples onto a coordinate system which is related to a map projection (Beyer 1983). Geometrically corrected images are needed in order to, locate any common points of interest in different scenes of the same area, and to overlay scenes of the same area taken at different times or with different sensors (Gordon 1981).

The Landsat-TM image used for this study was transformed to the British National Grid coordinates system. The imagery was corrected using an affine transformation with polynomial coefficients estimated from Ground Control Points (GCP). The resultant imagery was resampled to give 30m square pixels using a cubic convolution technique on the GEMS image processing system. A GCP is a specified feature which can be identified from 1:50,000 Ordnance Survey maps and expressed as a British National Grid coordinates. These GCPs were accurately located on both the ground and maps (using map coordinates), and also on the TM image (using

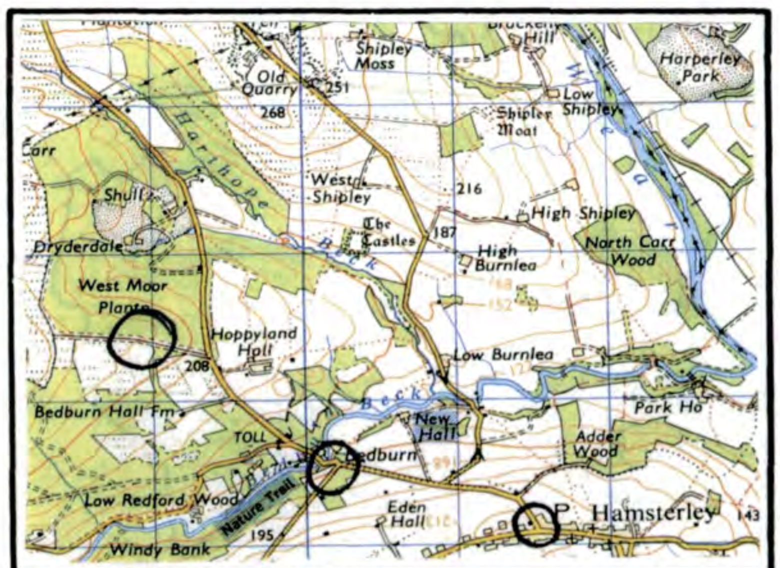
Fig. 5.2 Examples of Ground Control Points used for the Geometric Correction of Landsat-MT data used in this study



a) Rivers and Reservoirs



b) Motorways and Road's Junctions



c) Forests and Woodland areas

○ GCP

pixel/line coordinates). Therefore, it was necessary to choose features clearly visible on both the image and the map. Examples of the GCPs used are shown in figure 5.2. The following are some examples of the GCP's used.

- River Wear, River Tees, and River Browney, i.e. prominent bends or river junctions with tributaries.

- Road junctions such as A1(M) Motorway and other roads like A690 and A691.

- Corners of forests and the crossing of forest rides, such as Hamsterley and the Stang Forests.

- Stream and reservoir junctions, i.e. Balderhead, Hury, Com Green, Burnhope, Selset, Hurworth Burn, and Derwent Reservoir.

30 such GCPs were used to give an even distribution throughout the County and for a short distance into neighbouring Counties. A Root Mean Square (RMS) figure of 25 metres was obtained. Thus the satellite imagery has been geometrically corrected to the Britsh National Grid to an assessed accuracy of less than one pixel.

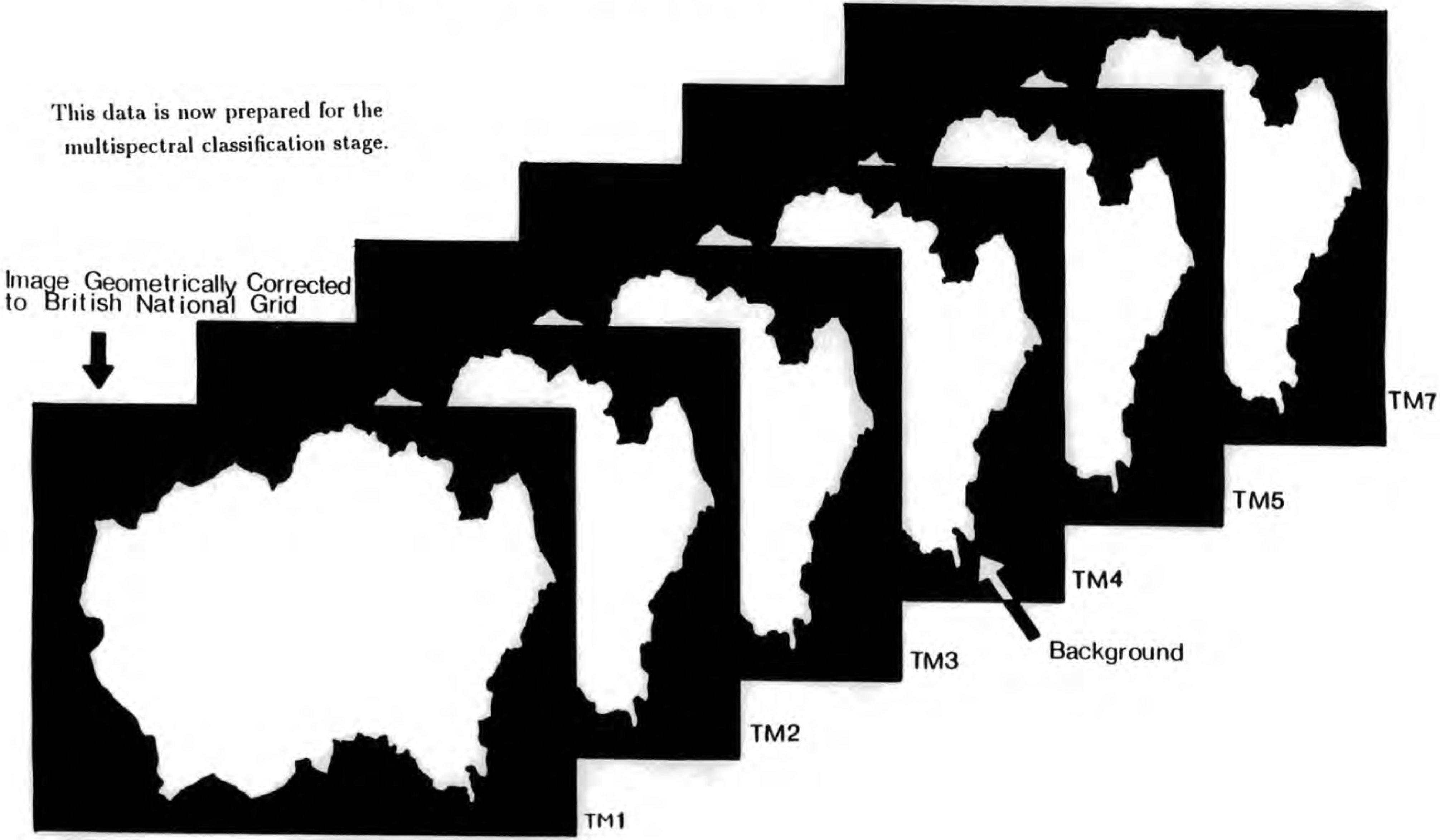
5.2.2. County Boundaries Digitization

The digitization of the county boundary was needed in order to make crop area estimates on the county basis. This process was carried out using the software supplied with the GEMS image processing system at ERSAC Ltd.

The boundaries digitized are those defined by the 1:50,000 OS maps dated 1976 (see section 3.4). Specialist digitising equipment was not available, but the Gemsone Image Processing Software could be adapted to perform a similar function but by a more time-consuming process. Using the interactive facility, a line could be drawn on the image representing the County boundary by closely comparing image and map detail. Using 512 $\times$ 512 image extracts, the County boundary line was constructed as a raster image file containing digital values of 255 for the line and zeros elsewhere.

Once the irregular polygon of the County boundary was completed, the area of the County could be "filled in" as values of 255. This could then be used as an image mask on the satellite image data to produce six final image files. These were bands 1 to 5 and band 7 of TM data, masked so that any image data outside the county was set to zero, with values within the County remaining unaltered. This is illustrated in the diagram shown in figure 5.3.

Fig. 5.3. Illustration of the Pre-processed TM Data



5.2.3. Stratification

In the field survey the county was divided into five strata and this approach was also applied to the TM data. Stratification was achieved by subdividing the TM image into five strata as illustrated in figure 5.4 before the classification was carried out. Finally, the classification results were tabulated to give the final crop type area estimation for each stratum independently.

Stratification is important where there is a large degree of homogeneity within each stratum. This may be important where Landsat-TM data is used for agricultural area estimation over large geographic areas. In this study stratification of the Landsat-TM image was applied for the following reasons.

i) To reduce the confusion between different classes which may in turn, improve the overall classification accuracy (Hubbard 1985). By using stratification the resulting strata will have less inherent internal variation. For example, in this study altitude was seen as a sensible variable on which to base the stratification of the scene. This allowed the separation of upland from lowland which closely reflects changes in farming practices. When choosing areas to represent each land use or crop type the stratification of the area allowed that only statistics from cover types known to exist within the stratum to be sampled. These areas are used to 'train' the classifier to recognise statistically similar areas. The 'within stratum sampling' helps to ensure that the areas selected are truly representitive of the cover types chosen.

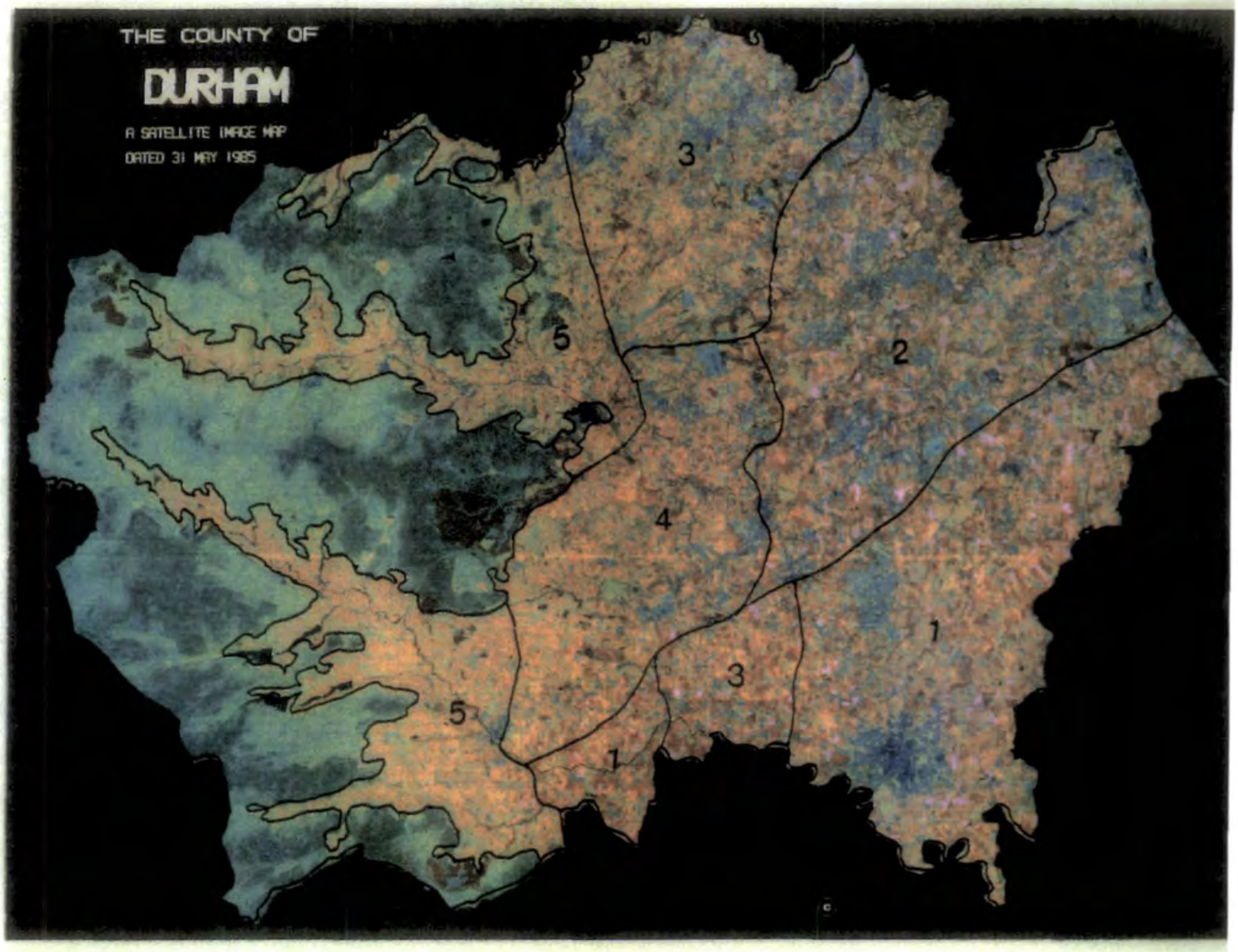
ii) It was easier to rectify any problems of poor classification results on a stratum basis. Differences were apparent between different parts in the study area. For instance, a small part of the the area covered by stratum 2 was covered by haze. This affected the results of the classification for this stratum. As will be detailed later, this problem was tackled by selecting different training data from the area which was affected by haze.

In this study, field size was taken as the main criterion for the image stratification because it relates to the following interrelated variables :-

- Agricultural intensity.
- Type of farming.
- The elevation difference.

As described in chapter two, farming intensity increases as one moves from the west to the east of the county. The livestock farming in the west makes the enclosed field size very small in this part of the county. The east of the county has large fields used for arable farming and in particular, cereals where large combined machinary is used. Taking these factors into account, the image was divided into five strata (see figure 5.4) which relate to the physical characteristics of the county.

Figure 5.4. The Main Strata in the Study Area



5.3. IMAGE CLASSIFICATION

5.3.1. Classification Problem

The aim of the classification is to find a decision rule for which each pixel in an image is assigned to corresponding class of land-cover. The Landast-TM sensor has seven spectral bands, these are

TM1 0.45 - 0.52 μm

* TM2 0.52 - 0.60 μm

* TM3 0.63 - 0.69 μm

* TM4 0.75 - 0.90 μm

* TM5 1.55 - 1.75 μm

TM7 2.08 - 2.35 μm

TM6 10.40 - 12.50 μm

From the theory of the absorption properties of matter and a knowledge of how complex surfaces interact with sunlight, it is possible to use the Landsat-TM spectral bands to discriminate between surfaces according to physical factors such as surface composition, surface texture and surface moisture characterestics or plant physiology. Electromagnetic energy reflected in the particular wavelength of each TM band is quantised to an 8 bit range (0 black and 255 white). The resultant data forms a featurespace in seven dimensions with each TM band representing one of the axes. Pixels of similar spectral response within this feature space will be grouped. The main purpose of the classification process is to identify these groups and place class boundaries around selected groups.

---

* *Bands selected for this study*

In this study four TM wavebands were used - TM2 (0.52-0.60 μm) because of its strong reflectance by plant pigments ; TM3 (0.63-0.69 μm) because of its high reflectance from non-vegetated surfaces and strong absorption by water and its absorption by chlorophyll ; TM4 (0.75-0.90 μm) because of its very high reflectance from vegetated surface and very strong absorption by water ; TM5 (1.55-175μm) because it allows subtle variations in absorption by water to be detected whilst still retaining high reflectance from vegetated surfaces (Curran 1984). Therefore, the data analyzed combined four spectral values for each pixel reduced from a possible seven spectral values. This reduced the amount of the spectral information used in the classification process while retaining the most important descriminatory information.

5.3.2. Supervised and Unsupervised Classification

Classification of Landsat data involves the adoption of a supervised or an unsupervised approach. Supervised classification imposes the analyst's knowledge of the area on the analysis to constrain the results, while an unsupervised approach determines the inherent structure of the data unconstrained by external knowledge about the area (Schowengerdt 1984).

In supervised classification, the analyst identifies training areas to determine their spectral characteristics. The spectral signatures of the pixels of these chosen areas are then calculated and used to recognise pixels with similar signatures throughout the image.

An unsupervised classification approach is used in remote sensing for many different applications as its main advantage is that no prior knowledge is needed to produce a classification map (Drake *et al*, 1987). In unsupervised classification, training data are not used, instead, a clustering technique is applied. The main process uses an algorithm to examine a large number of unknown pixels and cluster them on the basis of spectral groupings present in the image (Colwell 1983). Unsupervised clustering is applicable when it is difficult to choose homogeneous training areas of sufficient size. It is particularly appropriate in situations where the variations within and between the classes are not adequately described by the available reference data, and where spectral classes are expected to relate well to the vegetation classes.

In unsupervised classification, remote sensing data sets are classified by dividing up the measurements space (feature space) into non-overlapping decision regions which represent different spectral classes (Swain and Davis, 1978). These spectral classes defined by the clustering method are used to classify the image, but at this stage the analyst does not know what cover type is defined by each of the spectral classes. Once the classification is completed the analyst will identify the cover type represented by each spectral class using available reference data. The technique does not use statistics taken from known training areas, but rather the number of spectral classes into which the data are to be divided are computed. This is the main reason why the classification process using this technique is termed "unsupervised".

In summary, the main distinction between the supervised and unsupervised methods relates to whether the analyst chooses to 'train' the classifier or alternatively, allows the classifier to determine its own grouping (Hubbard 1985). It is also possible to combine both methods to produce more successful results (Davis and Swain

1974 ; Swain and Davis 1978 ; Schowengerdt 1984). This is because the supervised training does not necessarily result in class signatures that are numerically separable in feature space, and because unsupervised approach does not necessarily result in classes that are meaningful to the analyst (Schowengerdt 1984). In this study, a supervised method of classification was used because it is important to produce classes which relate specifically to land use categories in County Durham. An unsupervised approach would not necessarily reproduce these pre-defined classes.

5.3.3. Adopted Approach

Following the brief review of classification methods, subsequent sections describe the analysis and the details of the training data collection A supervised approach was conducted using different training areas chosen to include the range of land cover types present in each stratum of the county. The land cover classification system used in this procedure is described in section 4.6.2. The classification of the image was carried using a software on two image processing systems :-

- GEMS (made by Computer Aided Design Centre, U.K) at ERSAC.
- I^2S model 575 (made by International Imaging System, USA) at the University of Durham and University College, London.

Based on the criteria mentioned in section 5.2.3, the image was subdivided into the main five strata and the classification was performed on each stratum separately. The steps undertaken to produce an the image classification are illustrated in figure 5.5. This consists of the following procedures :-

(i) Select the training data from the existing map data.

(ii) Calculate the mean, standard deviation and covariance matrix for each training set for each cover type.

(iii) The statistics obtained are then used to define a maximum likelihood function which is in turn applied on a per-pixel basis to the whole scene. This then resulted in an image in which every pixel was assigned to a specific class or defined as unclassified.

(iv) Classification results were tabulated to produce crop area estimates for the classified image and for each selected sampling unit in the image.

In the classification process, the following considerations were taken into account.

1. The classification is made to suit the needs of the land cover classification system developed for the study area (see section 4.6.2).

2. The crops included in the classification were selected on the basis of their economic importance in the country (see section 2.6).

3. The availability and quality of ground reference data for each selected class.

4. Some of the fields identified as belonging to specific cover types were grouped into training fields and test fields. The training fields were those sites which selected to define the maximum likelihood function, while the test sites were used to check whether the pixels grouped by the classifier into specific classes, were correctly assigned.

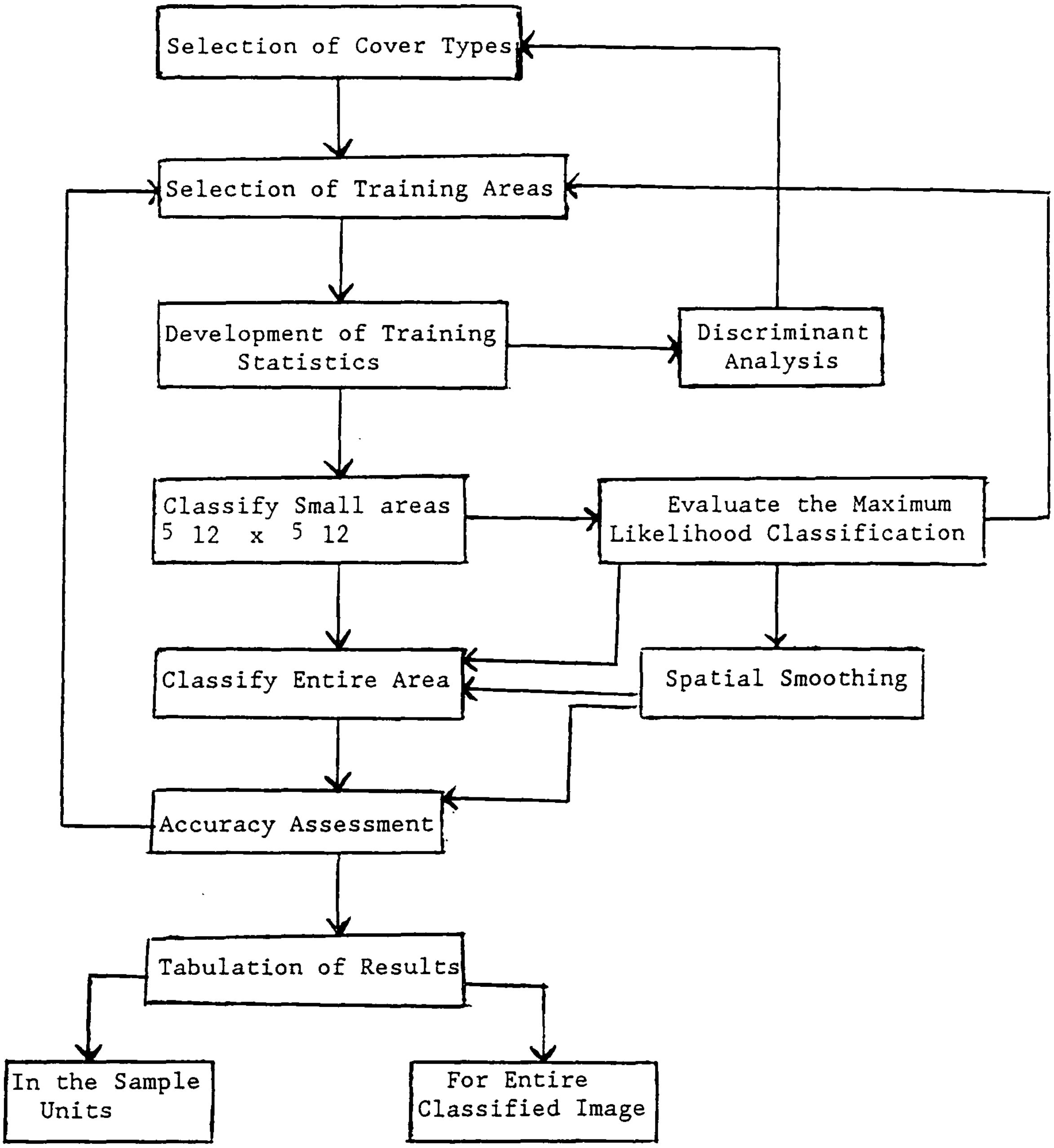


Figure 5.5

Adopted supervised approach to image classification.

5.3.4. Selection of Training Data

The following classes were chosen from level V of the land use classification system designed for County Durham .

1. Oil Seed Rape

2. Winter Wheat

3. Spring Wheat

4. Winter Barley

5. Spring Barley

6. Potatoes

7. Managed Grass

8. Cut Grass

9. Rough Grazing

10. Forestry

11. Heathlands

12. Moorlands

13. Reservoirs and Rivers

14. Bare Soil

15. Urban:Residential

16. Urban:Commercial and Industrial

17. Quarries (including Sand and Gravel works).

In order to train the maximum likelihood classifier, representative regions for each cover type must be identified. These regions, known as training fields, are

> *data samples of known identity used to determine decision boundaries in the measurement of feature space prior to the classification of the overall set of*

data vectors from a scene. (Swain and Davis 1978)

Within such areas, however, pixels are strongly correlated and may not be representative of the unit or class as a whole (Drake *et al* 1987). To avoid this problem, an adequate number of pixels must be chosen from different areas throughout the image since the training data can significantly influence the resultant classification accuracy (Swain and Davis 1978 ; Drake *et al* 1987 ; Mather 1987).

The training data selection procedure had to meet the following criteria :-

(i) The cover types of the fields selected for training had to be positively identified both on the ground and on the satellite imagery. Fields from cloud and haze covered areas were not selected as training sites.

(ii) The training fields had to be homogeneous and adequately represent the variation within each cover type throughout the area to be classified. Therefore, training sets were selected on the basis of homogeneity in terms of :-

- topographic and elevation,
- atmospheric effects, and
- farming system pattern

To fulfill these criteria, the stratified approach mentioned in section 5.2.3 was adopted.

For each class or land cover type it was necessary to choose more than four homogeneous areas distributed through each stratum. To represent the entire class the training areas were chosen from different locations. The selection of those areas of the same class were dependent on the stratification criteria and so it was important to select the training fields on a stratum basis. Because the study uses Landsat-TM data obtained in 1985, it was necessary to have training areas where the cover types were known for that date.

The training data were obtained from the following sources :-

(i) Fields with known cover types in the sampling units based upon information gained during the field survey. These sampling units were chosen by applying stratified random sampling approach.

(ii) From the main farms in the county which keep records of all the daily farming practices in 1985. Houghall Farm was one of the main farms chosen for this purpose. The information kept in the records of farms were compared where possible with details given orally by farmers. A number of farmers interviewed by the author were unsure about the state and distribution of their crops in 1985. Where written records were not kept it seems likely that the details given from memory alone may be in error. Such data were not considered accurate enough to be used as training sites.

Because of the nature of the growth stage of a number of crops cultivated in the county, it was necessary to chose those with discriminable stages of growth at the time of the image acquisition. Therefore, a number of crops included in level V of land cover classification system designed for the study area were excluded from the final classes included in the TM classification. These crops, such as spring barley and potatoes had a minimum leaf area cover at the end of May and were grouped together with the cut grass category. Spring wheat was also excluded from the classification because the area devoted to its cultivation in the county is very small. For urban, commercial and industrial areas, it was difficult to identify different training areas for each of them and so one class was considered to be appropriate. Other land cover classes with small areas were included together in one class call "unclassified". This class also includes quarries and sand and gravel works. The final land cover class scheme included in the classification process is illustrated in table 5.1. The training sets for each of these land cover classes were selected based on the criteria mentioned earlier.

Table 5.1
Land Cover Classes Included in the Classification

Class No.	Class	Annotation Key
1	Oil Seed Rape	OSR
2	Winter Wheat	WW
3	Winter Barley	WB
4	Bare Soil	BS
5	Cut Grass, Spring Barley, Potatoes.	CG,SB,PO
6	Managed Pasture	MP
7	Rough Grazing	RG
8	Forest	F
9	Heathlands	H
10	Moorlands	M
11	Reservoirs and Rivers	W
12	Residential	R
13	Commercial and Industrial.	CI
14	Unclassified	UN

5.3.5. Development of Training Statistics

The training areas for each cover type were selected and the covariance matrix for each class was calculated in order to define a maximum likelihood function. Because a number of the chosen classes, such winter barley, winter wheat and managed pastures, appear spectrally similar, it was necessary to investigate the statistical separability of these classes. Therefore, a discriminant analysis was carried on the statistics derived from their training data. The main objective of this analysis was to identify particular problems of spectral overlap from the statistics obtained for each class. This may indicate classes that have been badly defined or located closer together than originally thought.

The discriminant analysis was carried using the $SPSS^x$ computer statistical package at the computer centre of Durham University. The results of the analysis are illustrated in figure 5.6. To further investigate the degree of separability between classes the mean of DN values for each class was plotted for the TM spectral 2, 3, 4, and 5 in figure 5.7. Because winter wheat (WW), winter barley (WB), and managed pastures (MP) appear spectrally similar, it was necessary to further investigate the statistical separability between these classes. Therefore, the mean $\pm$ the standard deviation for each class of WW, WB and MP were plotted in figures 5.8, 5.9 and 5.10. It is clear from figures 5.8, 5.9 and 5.10 that WW, WB and MP cannot be clearly separated them especially in the visible wavebands (TM2 and TM3). It was thought that winter wheat and winter barley could be combined as winter cereals. However, because of their economic importance in the agricultural economy of the county, both crops were analysed independently. The implications of this decision will be discussed later when the assessment of classification accuracy is made.

Figure 5.6

DISCRIMINATION ANALYSIS LANDSAT-TM DATA FOR COUNTY DURHAM MAY 198[illegible]

SYMBOLS USED IN PLOTS

SYMBOL	GROUP	LABEL
1	1	OILSEED RAPE
2	2	WINTER WHEAT
3	3	WINTER BARLEY
4	4	BARE SOIL
5	5	CUT GRASS, SPRING BARLEY AND POTATOES
6	6	MANAGED PASTURES
7	7	ROUGH PASTURES
8	8	FORESTS
9	9	HEATHLAND
0	10	MOORLAND
A	11	WATER
B	12	RESIDENTIAL
C	13	COMMERCIAL AND INDUSTRIAL
*		GROUP CENTROIDS

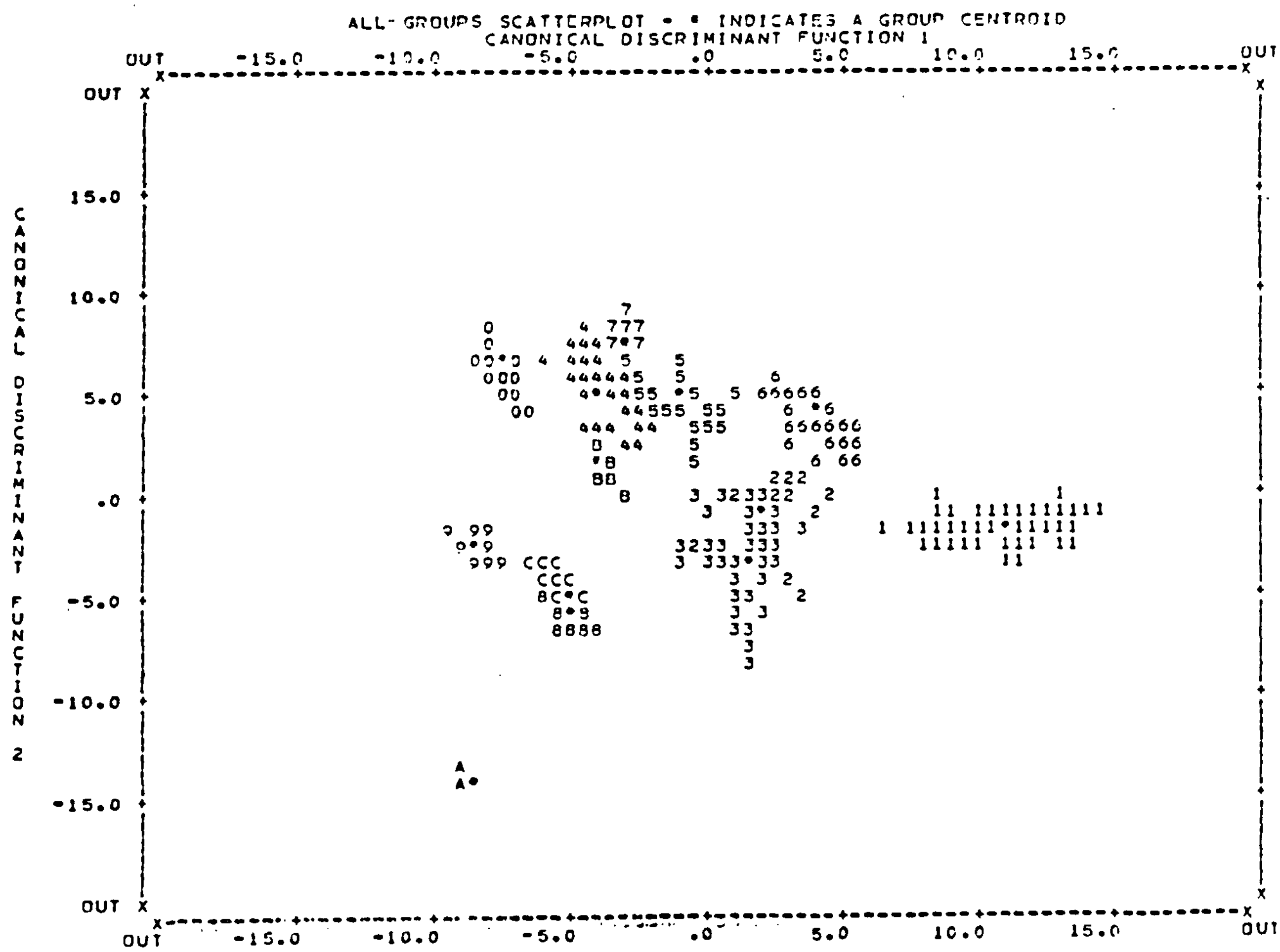
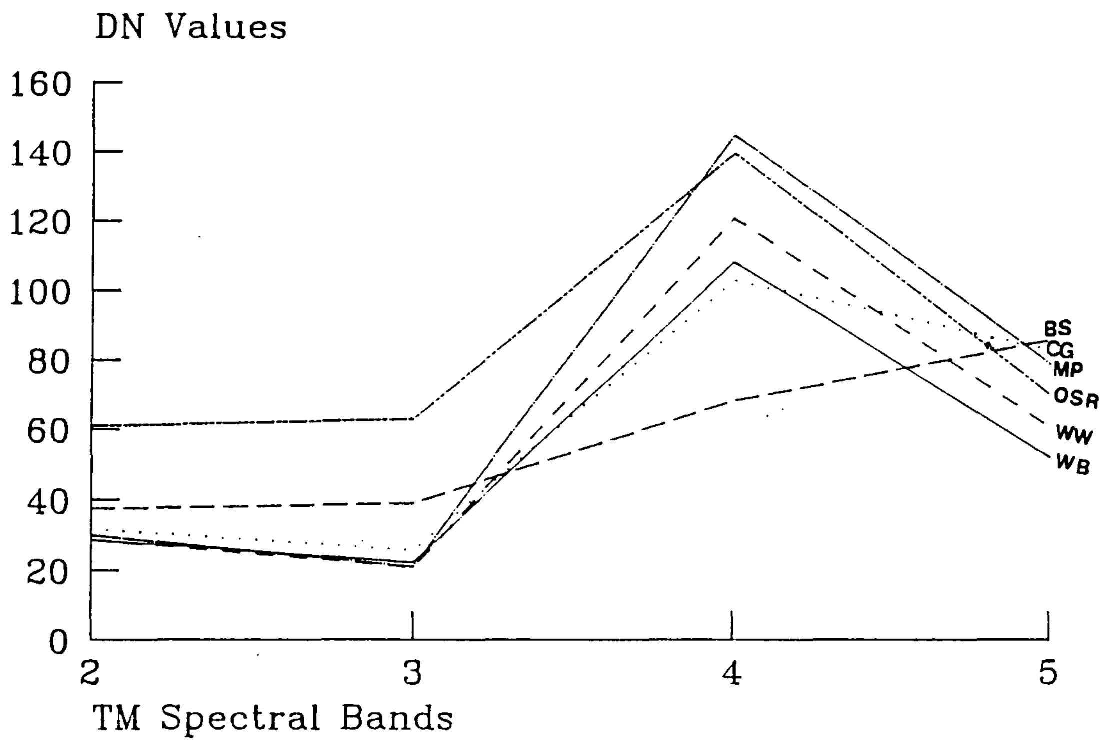
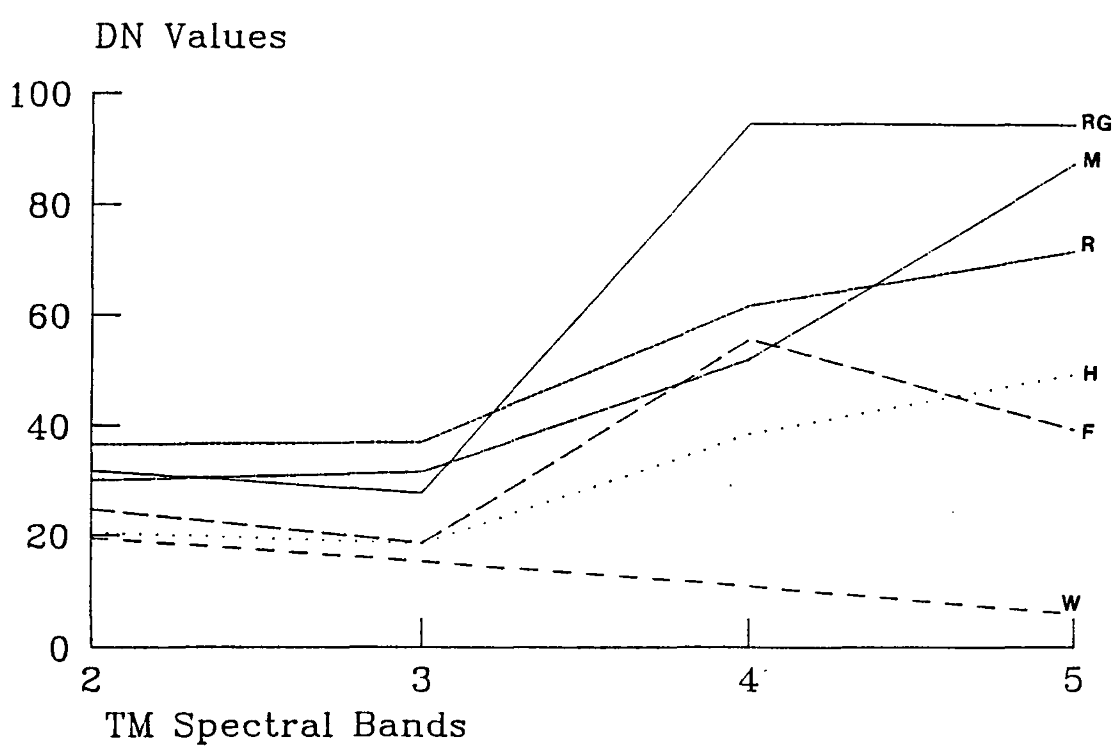


Figure 5.7 Plot of the spectral values for land cover classes for each of the reflectance TM bands. Data represent the means.





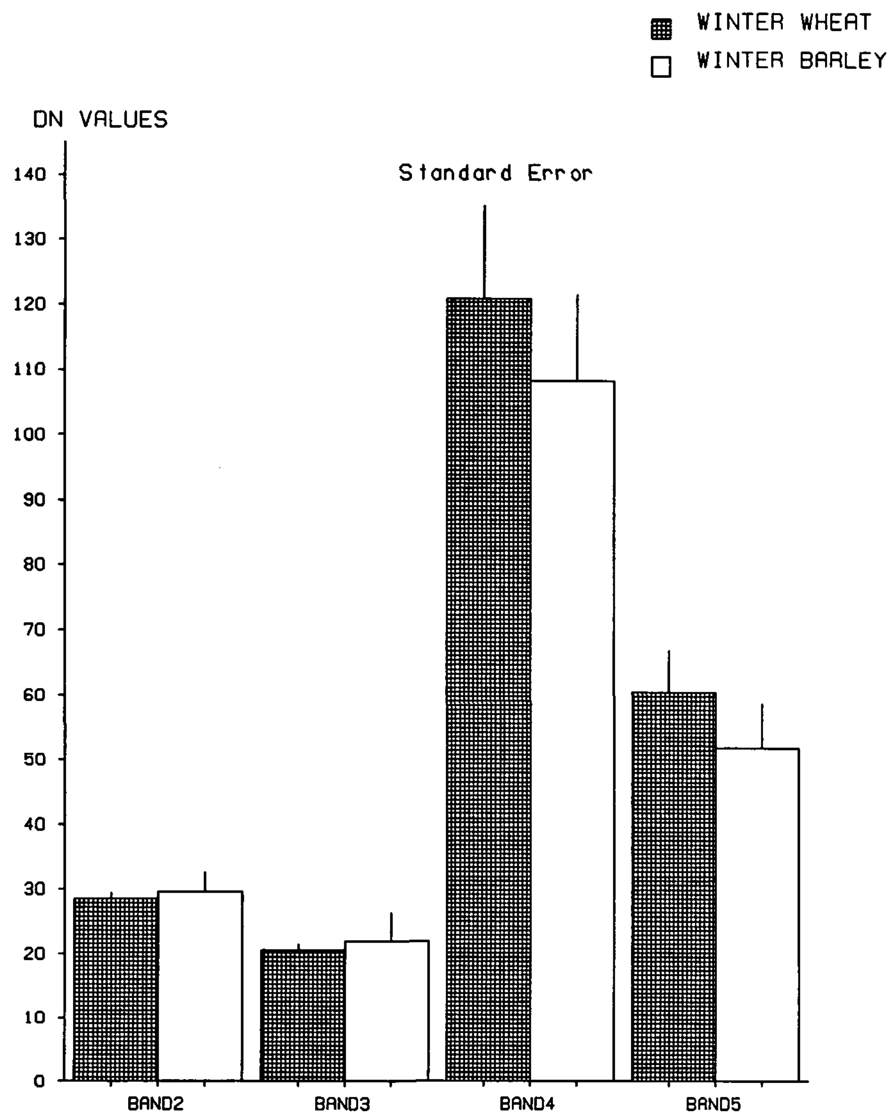


Figure 5.8 Plot of the DN Values for Winter Wheat and Winter Barley for TM Bands (data values represent means ± SD). The data represent statistics of different training sites form different strata over the study area

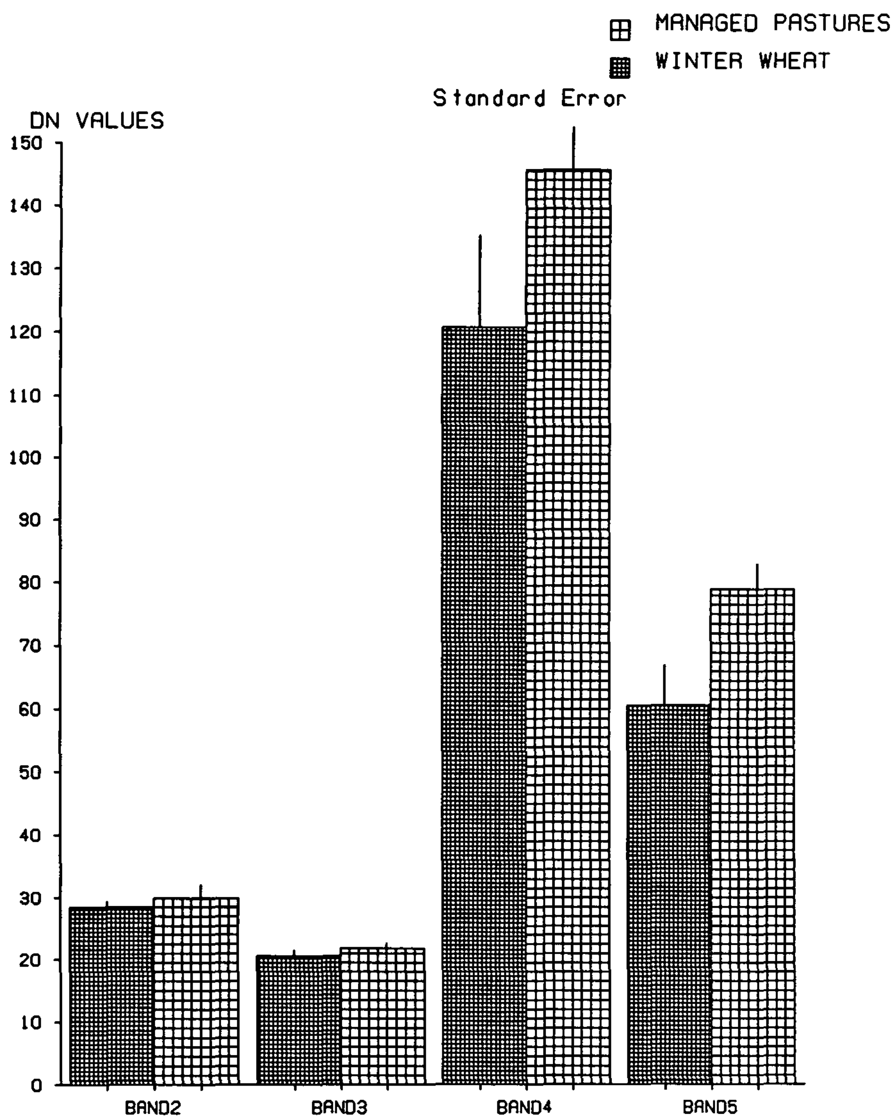


Figure 5.9 Plot of the DN Values for Winter Wheat and Managed Pstures for TM Bands (data values represent means ± SD). The data represent statistics of different training sites obtained from different strata over the study area.

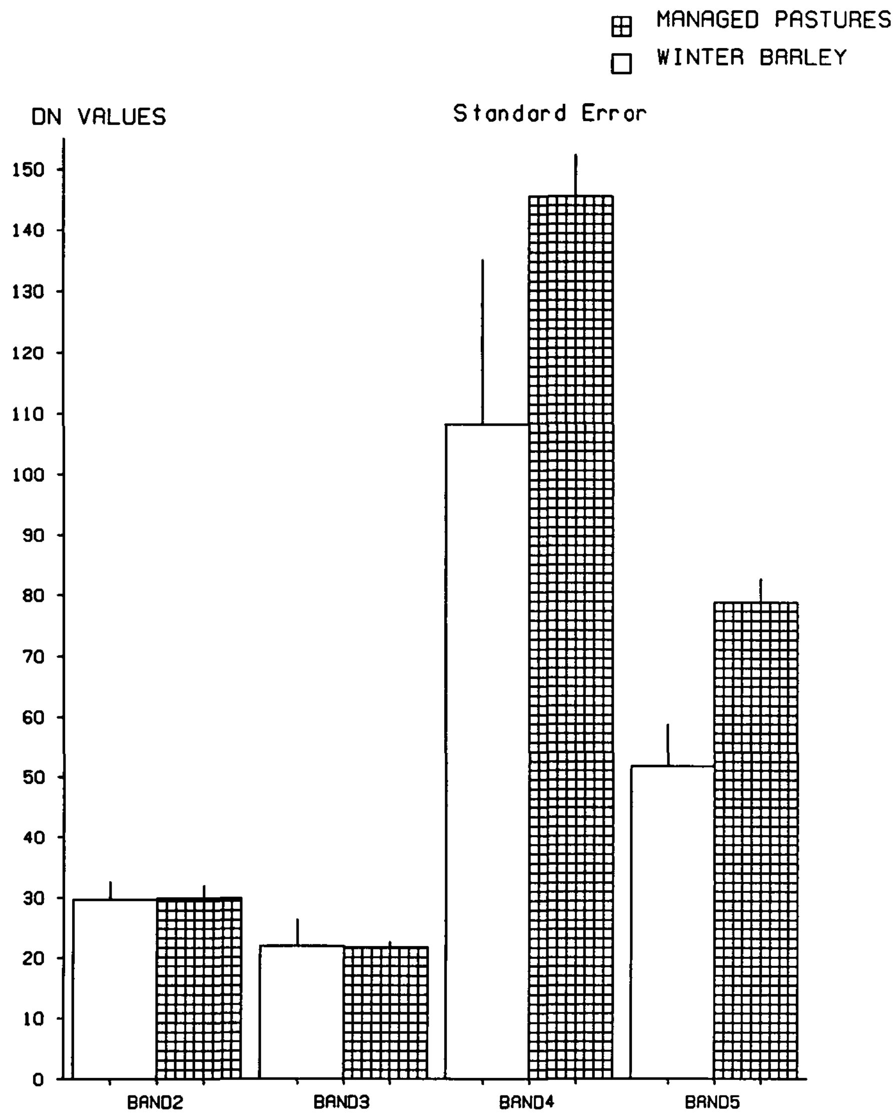


Figure 5.10 Plot of DN Values for Winter Barley and Managed Pastures for the TM Bands (data values represent mean ± SD). The data represent statistics of different training sites obtained from differen strata over the study area

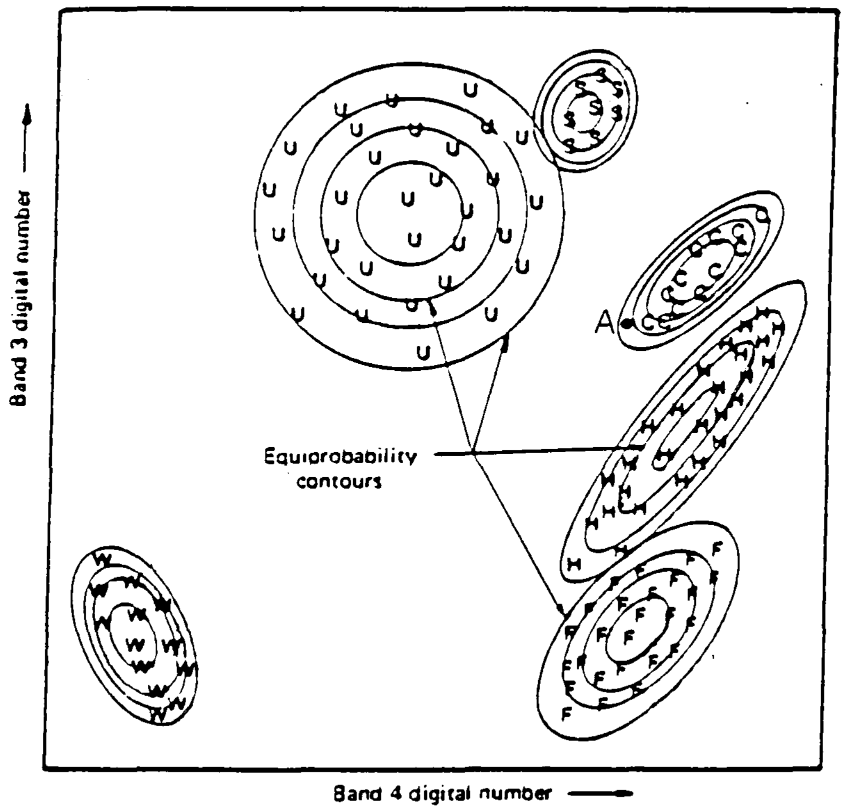
5.3.6. Maximum Likelihood Classification

The statistics obtained from the selected training fields were used to run the maximum likelihood classification. This classification technique is the most widely adopted technique for digital processing systems using satellite data (Hubbard 1985; Mather 1987; Settle and Briggs 1987).

Given the statistics obtained from the selected training data sets the statistical probability of a given pixel value being a member of a particular land cover class is computed (Colwell 1983). From a knowledge of the prior probability of an allocation to each class, a conditional probability is calculated for each pixel according to its spectral values and this is compared to the class conditional probability density functions (estimated from each training set) for each class (Donoghue and Shennan 1986). Then the pixel can be assigned to the most likely class for which it has the highest probability of membership, or labelled as unknown if the probability values are all below the pre-set threshold (Swain 1978; Colwell 1983).

This likelihood process is performed individually for each pixel and every class. As shown in figure 5.11 a series of equiprobability contours are created around each class of the training points in n-dimentional space (Lillesand and Kiefer, 1979). Using 4 TM bands in the classification process in this study, the equiprobability contours will be created in only 4-dimensional space. The shape of these contours reflect the sensitivity of the likelihood classification to interband correlation. This can be explained by pixel A in figure 5.11 which would be approximately assigned to the C category.

Figure 5.11. Equiprobability Contours Defined by a Maximum Likelihood Classifier



Source: Lillesand and Kiefer (1979).

The maximum likelihood classification uses a probabilistic discriminant function in order to assign each pixel to pre-defined groups according to the statistical parameters estimated from the covariance matrix of each training set. The programme outputs a land-cover map shown in figure 5.12 where each colour represents a land cover class; black represents areas not assigned because they are spectrally different from any of the pre-defined classes.

Unfortunately, haze affected the area over Darlington. Figure 5.13 shows the haze affected area which covers a small part of the south east of the County. Here, many pixels were not assigned to a land cover class because because statistics from the pixels in this area were altered by the presence of haze in the atmosphere. To overcome this problem, the area affected by the haze was extracted as a separate image and classified independently and then rejoined to the original image. To carry out the classification on this area new sets of training data for all land-cover classes included in the area were chosen. Then, their statistics were computed and used to re-run the maximum likelihood classifier. The final classification produced using training fields from the haze affected area is shown in figure 5.14.

Figure 5.12

CLASSIFIED LANDSAT–TM IMAGE OF COUNTY DURHAM

UN	Unclassified
OSR	Oilseed Rape
WW	Winter Wheat
WB	Winter Barley
BS	Bare Soil
CG	Cut Grass
SB	Spring Barley
MP	Managed Pastures
RP	Rough Pastures
F	Forests
H	Heathland
M	Moorland
W	Water
R	Residential
CI	Commercial and Industrial

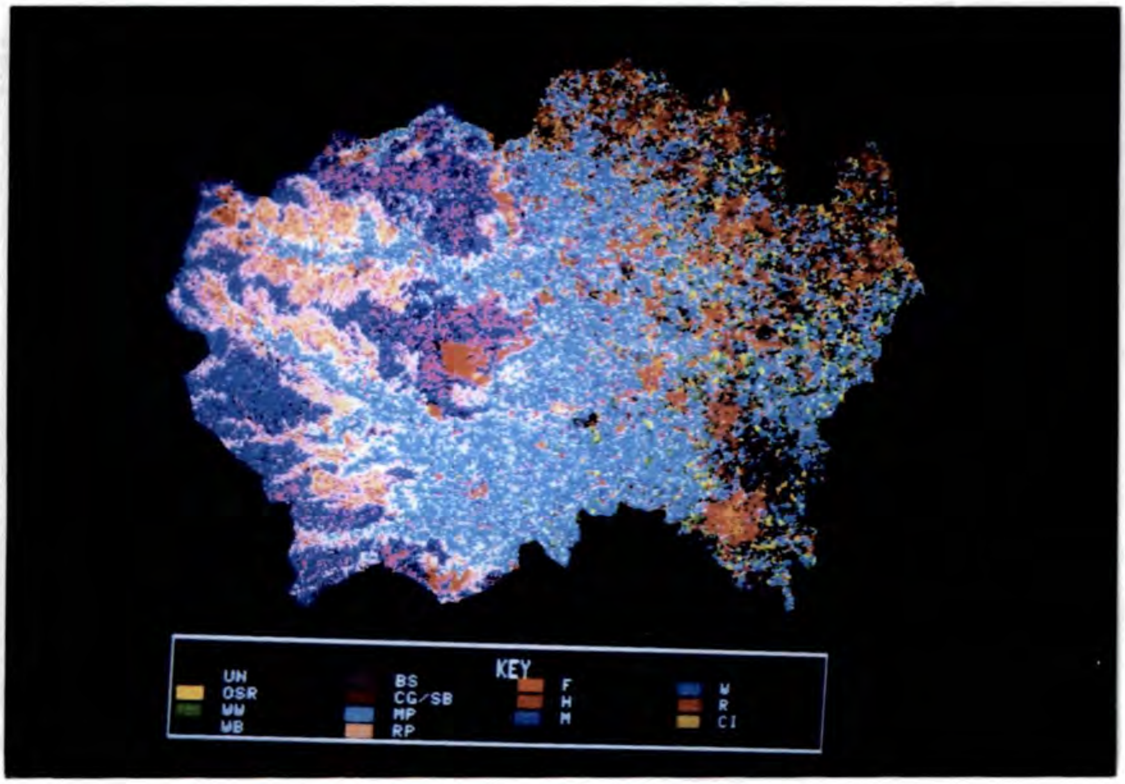


Figure 5.13 Landsat-TM False Colour Composite of Darlington

Showing the Area Affected by Haze

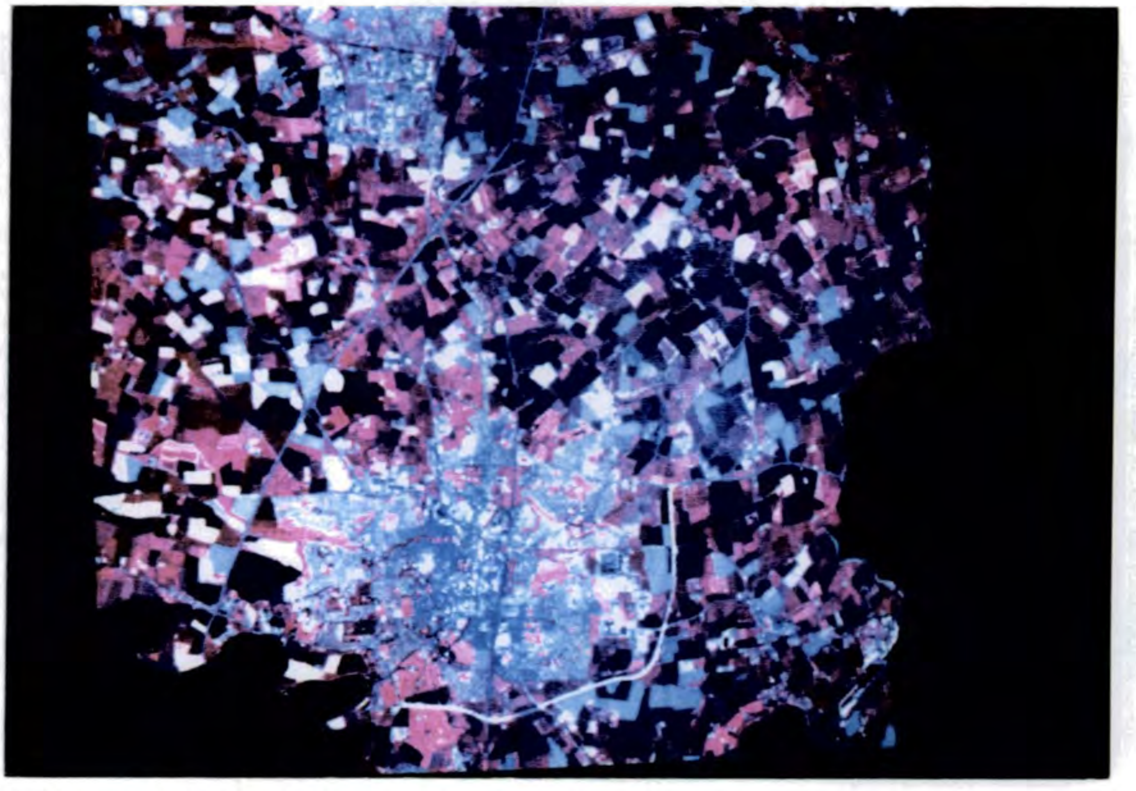
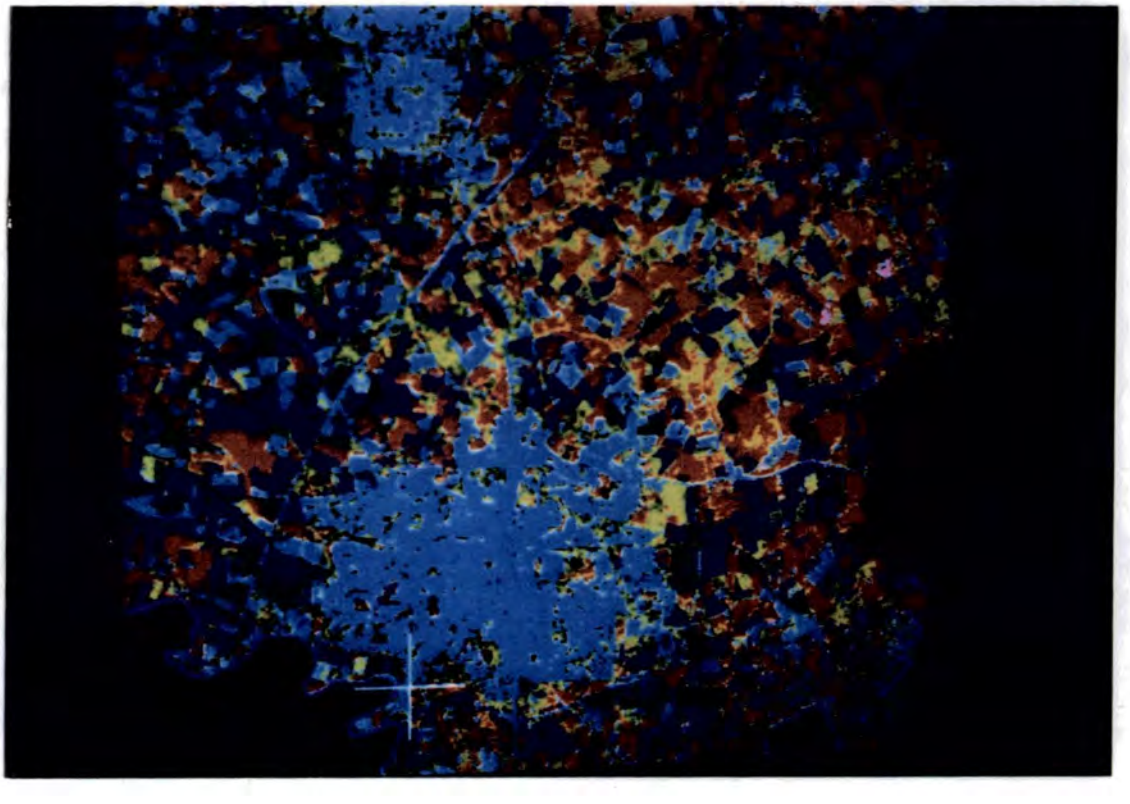


Figure 5.14 Land-Cover Classification of the Area Affected by Haze



5.4. POST-CLASSIFICATION DATA PROCESSING

5.4.1. Median Smoothing

Median smoothing is a technique often applied in order to improve the classification accuracy of remotely sensed data (Schowengerdt 1984; Drake *et al* 1987; Mather 1987). In this study median smoothing was applied as a post-classification process to remove isolated pixels to produce a less 'noisy' image. The accuracy of some classes such as urban and forests is improved by applying median smoothing (Hubbard 1985). The method was applied to the classified image in figure 5.12 in order to remove isolated pixels which may result from factors such as edge effects or from shadowing. This type of spectral confusion may be treated by comparing each pixel with its immediate neighbours and deciding on its allocation by a majority vote procedure (Schowengerdt 1984).

The technique is fully described by Mather (1987). If in a 3×3 matrix of pixels, the nine values in the neighbourhood including the point (x,y) are 3,1,2,8,5,3,9,4,27 then the median is 5 because it is the middle value in the data range. The median is preferred to the mean because

i. the mean is not represented in the original data, and

ii. the median is much less sensitive to extreme data values.

For instance, in this example the pixel value 27 will influence the mean but not the median. Thus, isolated extreme pixel values, which might represent noise, are removed by applying a median filtering technique. The method will also preserve the pixel edges. The final result of applying a 3×3 filter to this study is shown in figure 5.15.

Figure 5.15. A Land-Cover Classification of County Durham Produced From Landsat-TM, May 1985, With Median Smoothing

UN	Unclassified
OSR	Oilseed Rape
WW	Winter Wheat
WB	Winter Barley
BS	Bare Soil
CG	Cut Grass
SB	Spring Barley
MP	Managed Pastures
RP	Rough Pastures
F	Forests
H	Heathland
M	Moorland
W	Water
R	Residential
CI	Commercial and Industrial

5.4.2. Classification Accuracy Assessment

The assessment of the accuracy of the classification was carried on a separate set of test pixels from those used for training the classifier. There are two different types of accuracy assessment commonly used for crop classification (Mead and Szajgin 1982) :-

i. site specific, and ii. non-site specific.

The first technique involves statistical sampling of individual areas of known cover types. These areas must be designated as test fields and be different from the training fields. This method is effective for examining inclusive and exclusive classification errors for the various crops or cover types. The site specific technique requires more analysis effort (Hubard 1985).

Non-site specific methods for evaluating classification accuracy involve the comparison of area estimates produced by the classification and area estimates obtained by some other methods. Here the location of individual pixels is not important and so the method is suitable for use when the spatial arrangement of pixels is not critical.

Site specific methods are preferred here where the evaluation is made on a pixel by pixel basis and consideration is given to the spatial interdependence of the data.

For implementing an accuracy assessment method over large geographic areas, there are many difficulties in finding a workable method. These techniques are time consuming when applied to large areas. This may be problematic when the main reason for using remotely sensed data is the rapidity of the analysis. These methods would be more appropriate to be applied in small areas where suitable ground reference data will be smaller and thus sampling design will in some way have to be limited to these. In such cases classification accuracy assessment will need less field visits and therefore will not be as time consuming (Mead and Szjgin, 1982).

In this study, the cost and time were considered in implementing the assessment method of classification accuracy. Accuracy testing was carried out on fields in the sampling units (SU's) during the field visit. Taking the time and cost into account, the accuracy assessment

> "*should require that only the minimum number of field area necessary need be checked, yet ensure that results are still statistically valid.*" (Van Genedern and Lock, 1977).

The main idea was to minimize time and cost by implementing the adopted method, as mentioned by Mead and Szajgin (1982)

> "*The cost of an independent accuracy assessment can be minimized by collecting the necessary accuracy assessment data simultaneously with the training data. The data should be set aside during the classification process.*"

In this study the accuracy of the classification was assessed by using the known data obtained from the sampling units visited during the field work. The optimum sample size chosen for classification accuracy assessment in previous studies varied from 50 pixels (Hay, 1979), or 60 pixels (Rosenfield *et al* 1982 ; Hubbard 1985) to 400 pixels (Gurney, 1981) for each individual class. Taking into account the previous studies as well as time and cost considerations, test pixels in this study were determined to be 90 pixels for each individual class. It would be very time consuming to have the test data greater than this size for 13 classes because this would affect the practical application of the method.

Selecting the test fields from the sampling units has insured that the whole area was covered because they were chosen using a stratified random sampling. The sample pixels (n_i) for each class (i) were compared with the ground reference data and the accuracy was determined in percentage terms. This percentage was then multiplied by a weighting factor (w_i) which is calculated as the proportion of the area of this class cover to the total area of the image. To produce a mean accuracy estimate (p_{st}) for the classification in figure 5.12, equation 5.1 was applied as illustrated by Snedecor and Cochran (1967).

$$p_{st} = \sum_{i=1}^{k} w_i q_i \qquad 5.1$$

where

p_{st}= map accuracy mean estimate

w_i= weighting factor for class i

q_i= the percentage of correct pixels in class i

The variance of the estimate p_{st} is obtained from the equation

$$Var(p_{st}) = \sum_{i=1}^{k} w_i^2 p_i (\frac{q_i}{n_i}) \qquad 5.2$$

where

p_i = the percentage of incorrect pixels for class i, and

n_i = the sample size for the class i.

The confidence limit (cl_i) for the accuracy figures for each individual class (i) was obtained from the equation 5.3 (Snedecor and Cochran 1967).

$$q_i \pm 1.96\sqrt{p_i \frac{q_i}{n_i}} + \frac{50}{n_i} \qquad 5.3$$

where $\frac{50}{n_i}$ = correction for continuity, to improve the accuracy of the normal approximation.

The statistical accuracy of the maximum likelihood classification implemented in the study is illustrated in table 5.2. by applying equations 5.1, 5.2, and 5.3.

Table 5.2
Statistical Accuracy Test of the Maximum Likelihood Classification Shown in Figure 5.15

Class	OSR	WW	WB	BS	CG	MP	RG	F	H	M	W	R	CI	n_i	q_i	w_i	q_iw_i	cl
OSR	90													90	100	0.01933	1.933	
WW		65	15			10								90	72.2	0.04901	3.538	61.9 - 78.1
WB		12	61			17								90	67.8	0.06673	4.524	57.1 - 78.5
BS				80	5							5		90	88.9	0.13897	12.354	81.3 - 96.5
CG&SB				1	75		12		2					90	83.3	0.10764	8.966	74.5 - 92.1
MP		11	14			65								90	72.2	0.20783	15.005	61.9 - 78.1
RG					9		81							90	88.9	0.14642	13.017	81.3 - 96.5
F								90						90	100	0.03536	3.536	
H									80	6			4	90	88.9	0.02486	2.210	81.3 - 96.5
M				5					5	80				90	88.9	0.13864	12.325	81.3 - 96.5
W											90			90	100	0.00289	0.289	
R									7			75	8	90	83.3	0.05251	4.374	74.5 - 92.1
CI									10			10	70	90	77.8	0.00981	0.763	68.3 - 86.3
Total	90	87	91	85	90	102	95	90	104	85	90	90	85	1170		1.00000	82.835	

q_i=accuracy (%) for each class
w_i=class area weighting
cl=confidence limits (95%)

Overall map accuracy = sum of individual accuracies, each weighted according to the area of the map covered
= 82.8 % with 95% confidence limits of 80.4% - 85.3%

5.5. TABULATION OF LANDSAT-TM CLASSIFICATION RESULTS

The overall classification performance is better than 80%, for the most land cover classes which indicates that the classification should give accurate land cover estimates. To implement the methods used in this study it was important to estimate the hectarage for each crop type from the classified TM image, for

- the 44 sample units selected by applying a stratified random sampling approach
- each stratum in the study area
- the whole study area.

The estimates of hectarage for each different crop type obtained by Landsat-TM classification on a stratum basis are presented in table 5.3. Also the hectarage estimates of crop type in each sampling unit was estimated from the classified image. Each sample unit was located on the geometric corrected image by using its National Grid Coordinates on the 1:50,000 Ordnance Survey maps. The sampling unit then transferred to the classified image and each class pixels were counted in each one of these sample units. The area in hectares of each class then obtained by multiplying the total number of pixels by 0.09, which the area of the pixel in hectares. An example is given in Table 5.4.

Table 5.3

Crop Type Area Estimates Produced by Landsat-TM Classification (ha)

Stratum	Oilseed Rape	Winter Wheat	Winter Barley	Managed Pastures
1	1820.4	3961.3	5553.1	11201.9
2	2100.8	3145.8	6124.3	7243.4
3	671.2	3029.3	2756.5	17114.5
4	——	1363.2	777.4	21991.2
5	——	134.1	656.4	26699.3
Total	4592.4	11633.7	15867.7	84250.3

Table 5.4

An example of crop type area estimate produced from a classified sample unit using GEMS image processing system

Class (cover type)	Count (no. of pixels	%	Area (m^2)
1	74	6.401	66600
2	192	16.609	172800
3	312	26.990	280800
4	268	23.183	241200
5	196	16.955	176400
6	59	5.104	53100
7	38	3.287	34200
8	0	0	0
9	6	0.519	5400
10	0	0	0
11	0	0	0
12	0	0	0
13	11	0.952	9900
14*	0	0	0
15*	0	0	0
Total	1156	100.00	1040400

To obtain the hectarage estimate for each class either the number of pixels of each class multiplied by 0.09 or the class area (m^2) devided by 10,000 (the hectare area in m^2).

* Background Classes.

5.6. ANALYSIS OF FACTORS AFFECTING CLASSIFICATION ACCURACY

Factors which might have influenced classification results are discussed in order to understand and interpret the results. Low classification accuracy is likely to be the result of the following closely associated factors.

5.6.1. Land-cover Scheme Adopted

Some of the classification errors produced were related to the land-cover scheme adopted. These errors represent the errors of comission - in which another crop (confusion crop) is identified as a member of the target crop, or errors of omission - in which a member of the target crop is classified as another. It can be seen from examining table 5.2, the confusion matrix for the Landsat-TM classification, that there was confusion was between winter cereals and managed pastures.

As illustrated in table 5.2, the lowest classification accuracy figures are those of winter wheat and winter barley. The main reason for this confusion is that both crops have the same cropping cycle and are spectrally similar especially in the visible region of the electromagnetic spectrum. This is well illustrated in figure 5.16. Also, the managed grassland areas tend to be classified either as winter wheat or winter barley. Apart from these examples the overall classification results for these classes are good considering the wide range of DNs covered by these classes.

In order to distinguish between those winter cereals and grassland classes imagery from two or more seasons at the same site is strongly recommended. This was not possible under the circumstances of this study. However, the individual class accuracies (table 5.2) reveals a good classification accuracy for winter wheat, winter barley and grass land despite some confusion among them. Figures 5.16 shows the spectral separability between winter cereals and managed pastures in TM bands 2, 3, 4, and 5.

5.6.2. Ground Data

The collection of ground data is subject to error since the precise details of crops growing in May 1985 is often unknown. The main reason for this was the long period between the Landsat-TM image acquisition and the time of the field survey. The ground data were collected by interviewing the farmers in the sample units which also was subject to errors for reasons mentioned in section 4.7.5.

5.6.3. Landsat-TM Image Acquisition Date

The Landsat-TM image used for this study was acquired on 31st of May 1985. The time of the image was not suitable for all the crops in the area to be identified. The image was most appropriate for oilseed rape identification. As illustrated in table 5.2, the highest classification accuracy was obtained for oilseed rape. The main reason for this high value, is that oilseed rape was in its flowering stage which made the crop easy to identify spectrally because the characteristic yellow colour of its canopy.

For other crops such as potatoes and spring barley, the classification accuracy obtained was low. The May 1985 Landsat scene has proved to be inappropriate for identification of

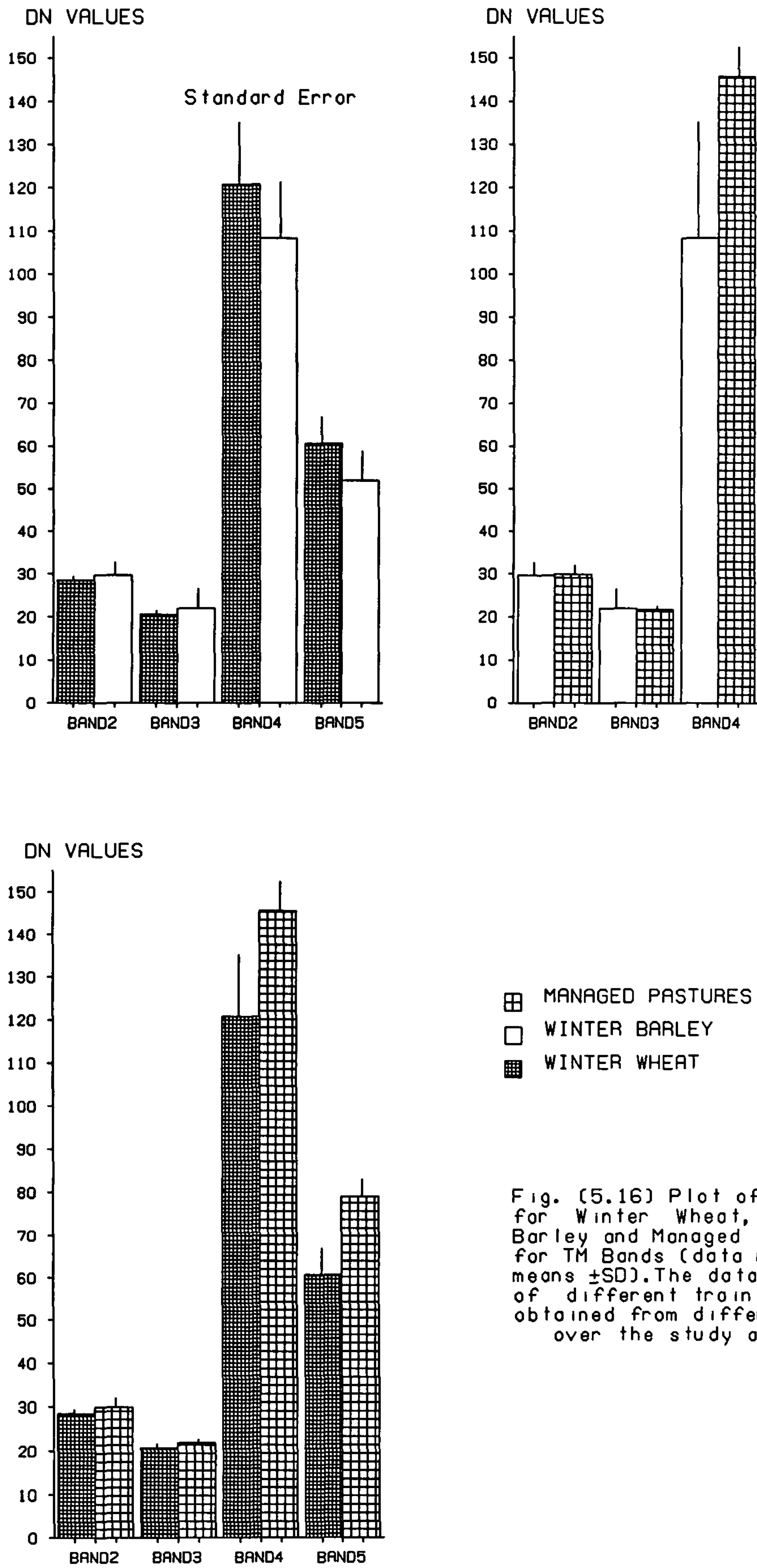


Fig. (5.16) Plot of DN Values for Winter Wheat, Winter Barley and Managed Pastures for TM Bands (data represent means ±SD). The data represent of different training sites obtained from different strata over the study area potatoes because the fields were recently planted and was in its minimum leaf area cover stage. For crop identification and area estimation of potatoes using Landsat-TM imagery, the last week in July to the first week in August is the best period for the TM image acquisition. The crop at this time of the year at the stage of its maximum leaf area which make it possible to be spectrally discriminated.

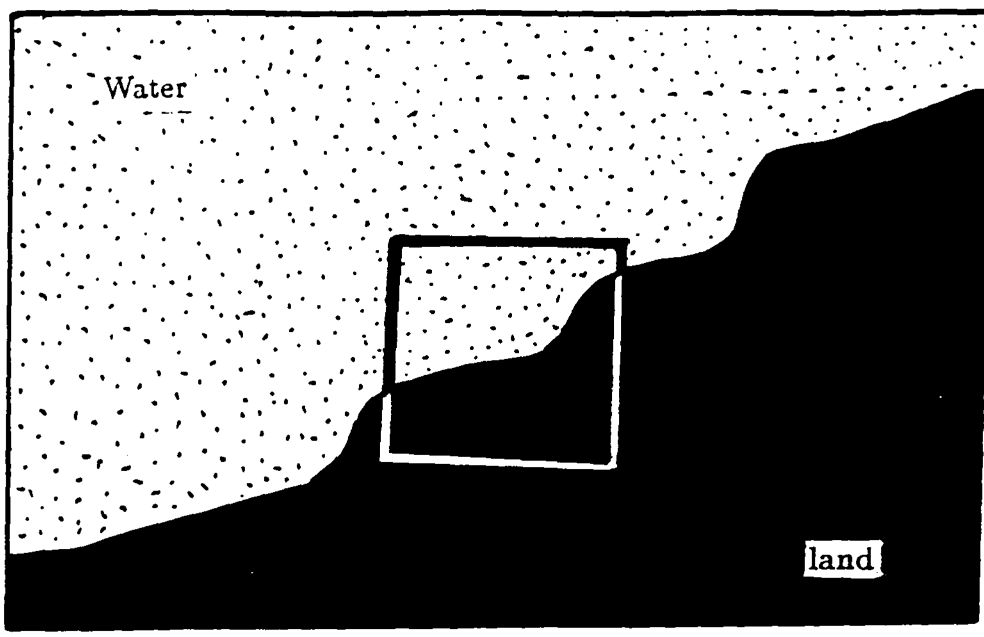
Spring barley is planted in April and its flat-leaf emergence begins in the first week of July. At this stage of growth the crop has its highest leaf area. Therefore, in order to identify it and estimate its hectarage in County Durham, the Landsat-TM image should be acquired in early July.

5.6.4. Boundary Pixels

Low classification accuracy may also attributed to the presence of spectral mixing of pixel values at the class boundaries. The degree to which accuracy is reduced is dependent on the proportion of these pixels within the image (Drake *et al* 1987). The use of higher spatial resolution data such as TM reduces the impact of the mixed boundary pixels by decreasing their proportion (Allan 1987). The Thematic Mapper sensor has 30m resolution which is sufficient for the classification of area of homogeneous vegetation stands larger than 30m. The problem of boundary pixels will arise where the vegetation cover varies considerably within a 30m area making the classification accuracy less reliable.

The most obvious example for the edge effect errors is the boundary between water and the land where a pixel in this area will be part water and part

Figure 5.17. Edge effect pixel misclassification of water/land boundary



Source: Hubbard (1985)

land. In this case, boundary pixels may been misclassified as heathland or shallow water. This example is illustrated in figure 5.17 (Hubbard 1985).

5.6.5. Aerial Photography

The aerial photographs used for this study were acquired during the summer of 1971 and were the only available complete air photo survey covering the county. Despite their usefulness, there were some problems associated with the use of air photos due to the changes which have taken place on the ground in the period between the date of the aerial photography, 1971 and the Landsat-TM 1985 scene. The main changes were alterations in

- Field boundaries
- New forest plantations
- Deforestation
- Open cast coal mines
- New roads
- Urban expansion

The author was aware of such changes and recorded them on the questionnaire. However, it was difficult to detect all such changes through the whole County. The changes were marked only for the sampling units visited through the field work. The method was time consuming to be applied for the whole study area, and the changes marked on the maps were not very precise. Therefore, the best time for aerial photography acquisition should be coincident with the Landsat image acquisition in order to avoid such problems and to increase the benefits of using remote sensing techniques.

Because of the high cost of obtaining a full aerial survey of the county, 1:25,000 Ordnance Survey maps can be used instead. As it is shown in figure 3.3 the field boundaries on the maps are very clearly detailed and can serve to implement the methodology of this study.

6.1. INTRODUCTION

To produce an accurate and timely estimate of the area of agricultural crops, a hybrid technique was applied which is based on the combined use of Landsat TM and field data. The technique used called double sampling, and its statistical basis was first described by Cochran (1953).

The purpose of this chapter is to outline the general methodology applied to obtain the crop type area estimates using the double sampling technique by combining Landsat TM data and ground measurements obtained by a field survey. The efficiency of using the technique over conventional method is assessed.

Section 6.2 describes double sampling approach in general and illustrates the some of the estimation techniques used. The adopted methodology for this study is described in section 6.3 and section 6.4. Results are discussed in section 6.5 and in the last section in this chapter is a statistical analysis of the different methods used for crop area estimation.

6.2. DOUBLE SAMPLING

The method is described by several authors including Cochran (1953), Wigton *et al* (1973), and Benson *et al* (1974). To illustrate the methodology of double sampling, it is important first to define multi-level and multi-phase sampling procedures. In remote sensing applications, multi-level sampling is mainly used to combine the satellite data with detailed information from ground based surveys or air photos. Multi-stage and multi-phase sampling are the main two types of multi-level sampling. In multi-stage sampling the population is divided into a number of sampling units which are sampled in an ordinary manner. These sample units in turn are subdivided into smaller second stage sample units which are also sampled. This type of sampling is usually used when it is difficult to establish a sampling frame at the primary stage of the survey.

Multi-phase approach differs from multi-stage in the fact that it requires that the population size be known and also the sampling frame can be established. The main differences between the two approaches is that in multi-phase sampling the size of sample units remain the same at each level.

Double sampling is a two-phase sampling technique which combines two sources of information. The approach is designed in order to increase the precision of an estimate by using supplementary information about the population being used. In the method, an auxiliary variable x which is correlated with variable y is obtained for each unit in the sample. This design takes advantage of the correlation between x and y. When this correlation is sufficiently large, a reduction in the variance of the estimate used is significant in comparison with a single-phase sampling based on y alone (Cappelletti *et al* 1982).

One of the main reasons for using the double sampling technique is to benefit from the statistical advantages of the supplementary information. For instance, an auxiliary data (x) may be used to reduce the bias and/or to increase the precision which result from the use of a single-phase sampling estimator based on y only. Also, the approach is based upon combining a less expensive variable to measure (x) with more expensive variable (y) to be observed.

The double sampling strategy uses the correlation between two information sources. This correlation is then used by one of the following estimators:-

a. Ratio estimator.

b. Linear regression estimator.

The estimation produced by either of these estimation techniques is based on two-phase sampling strategy instead of single-phase approach.

6.2.1. Ratio Estimator

The ratio method uses an auxiliary variable (x_i) in conjunction with y_i and a correlation coefficient (r) for both variables is obtained (Cochran 1977). The correlation coefficient is obtained by the formula

$$r_{xy} = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{y})(x_i - \bar{x})}{\sum_{i=1}^{n}(y_i - \bar{y})^2 \sum_{i=1}^{n}(x_i - \bar{x})^2}} \qquad 6.1$$

With ratio estimation the means of the sample are estimated and multiplied with the mean of the population total of the auxiliary data $\bar{X}$. The estimator

$$\hat{y}_{rt} = \frac{\bar{y}}{\bar{x}}\bar{X} \qquad 6.2$$

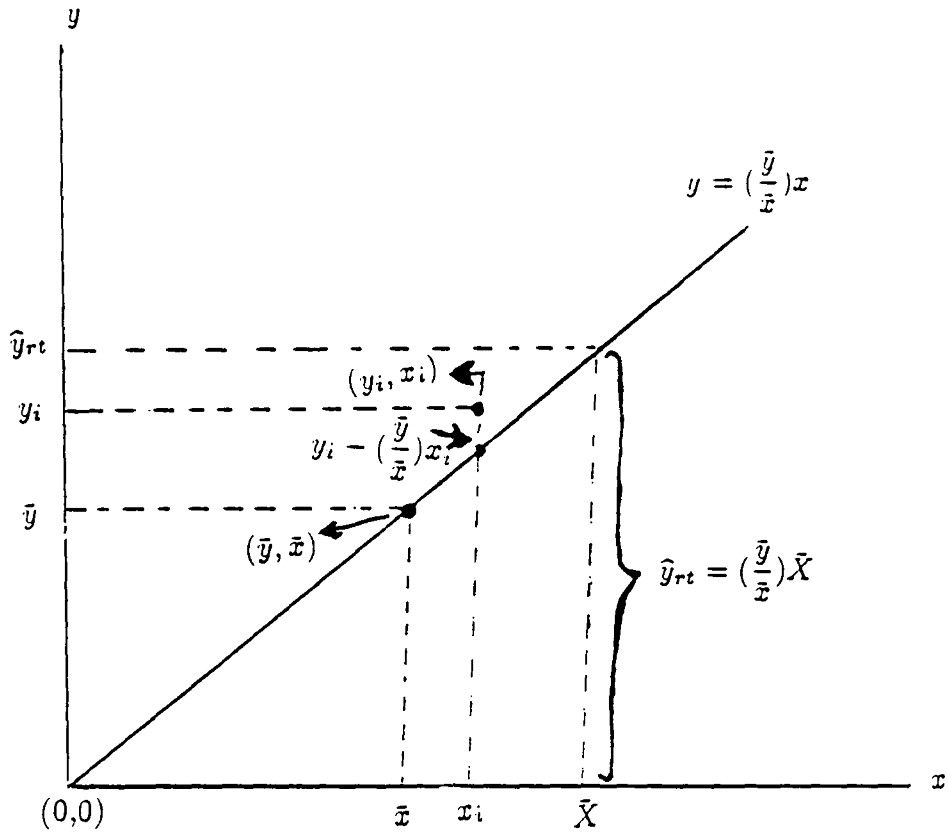
is the most common formula used for estimating the population mean $\bar{Y}$ (Williams, 1978). It is clear from the above equation that the population total of the auxiliary data ($\bar{X}$) must be known. Since the data are utilized in the form of a ratio, the estimator ($\hat{y}_{rt}$) is called ratio estimator. The sample variance of the estimation $Var(\hat{y}_{rt})$ can be calculated from the equation

$$Var(\hat{y}_{rt}) = \frac{1}{n(n-1)}\sum_{i=1}^{n}\left(y_i - \frac{\bar{y}}{\bar{x}}x_i\right)^2 \qquad 6.3$$

As it is clear from equation 6.3, if the linear relationship between x_i and y_i does not pass through the origin, the variance will be increased as well as the bias as a result of the increase in the deviation $y_i - \frac{\bar{y}}{\bar{x}} x_i$. This is well graphically illustrated by Williams (1978), and shown in figure 6.1.

Fig. 6.1

The Ratio Estimator, $\hat{y}_{rt}$



Source :- Williams (1978).

6.2.2. Linear Regression Estimator

Like the ratio estimate, the regression technique is designed to increase precision by the use of an auxiliary variable x_i (Cochran 1977). Both estimators utilize the correlation between x and y. This correlation is obtained by applying equation 6.1. The regression estimator is obtained by using the sample regression coefficient (b), which can be computed from the formula

$$b = \frac{\sum_{i=1}^{n}(y_i - \bar{y})(x_i - \bar{x})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \qquad 6.4$$

The linear regression estimator

$$\widehat{y}_{reg} = N[\bar{y} + b(\bar{X} - \bar{x})] \qquad 6.5$$

is used as the estimator for population mean $\bar{Y}$. The sample variance of $\widehat{y}_{reg}$ is calculated by

$$Var(\widehat{y}_{reg}) = N^2(\frac{s^2}{n})(1 - r^2) \qquad 6.6$$

where

$$s^2 = \frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n - 1} \qquad 6.7$$

There are a number of reasons why regression estimation is preferred to the ratio estimation. First, the linear regression technique is useful when the straight line describing the relationship between x and y does not pass through the origin. This is because in such a situation the ratio estimator may have both inflated bias and variance (Williams, 1978). Also, the ratio estimate is not always more precise than the simpler estimate $N\bar{y}$ (Snedecor and Cochran 1967; Craig 1989; Winings 1989).

It has been shown that the ratio estimate is more precise only if r_{xy} (the correlation coefficient between x and y) exceeds $\frac{CV_x}{2CV_y}$, where the CVs are the coefficient of variation (Snedecor and Cochran 1967).

The ratio estimate can only be used if the number of sample units in each stratum were sufficiently large to give reasonably accurate determination of the values of the ratio for the separate strata. If the sample units in the stratum are not large enough and there is a correlation between x and y, the ratio estimate will be biased (Yates, 1981). Therefore, the ratio estimate will be more accurate for stratum with large sample size. Regardless of whether the relationship between x and y passes through the origin or not, the bias resulted from using ratio estimator will be decreased as the sample size increases.

Despite all these limitations, the ratio estimator is simple to calculate and in many applied problems where the numbers of sample units included in the sample is large, bias is not a severe problem such as in population surveys.

Double sampling is applied in order to increase the precision of an estimate by using other ancillary data. In remote sensing applications, the technique was used in order to improve the precision of the acreage estimation of different agricultural crops (Cappelletti *et al* 1982 ; Pont *et al* 1982 ; Hafner *et al* 1982 ; Latham *et al* 1983). The technique was applied in order to increase the accuracy of area estimation based on the combination of Landsat data with different data sets ranging from aerial to ground surveys.

Many authors including Craig *et al* (1978) ; Hanuschak *et al* (1979) ; Craig (1980) ; Mergerson (1981) ; Cappelletti *et al* (1982) ; Cook *et al* (1984) ; Pont *et al* (1982) ; Proud *et al* (1982) ; Hafner *et al* (1982) ; Latham *et al* (1982) ; Angelis and Gizzi (1984) ; Redondo *et al* (1984), have studied the use of combining Landsat-MSS and ground data in order to estimate the area of agricultural crops. The main reason behind this combination is the fact that Landsat data can produce an acreage estimate over large geographic areas at a small cost per unit area. However, Landsat can produce a complete census for the whole area to be sensed which in turn result in no sampling error (imprecision). Despite all these advantages, Landsat data can have substantial measurement error (bias) as a result of misclassification (Latham *et al*, 1983).

To overcome the bias produced by the Landsat data, a double sampling approach was applied on the basis of combining Landsat data and other ground measurements to produce more precise and less biased estimates for the agricultural areas. The ground data were used because of its low bias because the ability of identifying crops accurately.

Hafner *et al* (1982) has studied the combined use of Landsat-MSS and ground measurements to estimate the area of different land-cover categories in Yemen. He examined whether the ground estimate could be improved by taking Landsat imagery into consideration. He found that, the area estimate is significantly improved by combining the ground data with those measurements obtained from Landsat image interpretation (Hafner *et al* 1982).

Latham *et al* (1982) used double sampling approach based on the combination of both Landsat-MSS and ground data to estimate the aerial extent of irrigated land in Gefara Plain, northwestern Libya. The results showed that the most precise estimates were those based on double sampling. This precision was higher than those obtained by ground survey or Landsat-MSS data when they were used separately (Latham *et al* ,1982).

Landsat-MSS data were used in conjunction with the ground data to estimate the area of corn and sorghum crops in Arizona (Craig and Miller 1980). In their study, Craig (1980) found that the estimates using Landsat and ground data jointly were more precise than those obtained utilizing ground survey alone.

Cappelletti *et al* (1982) estimated the cultivated area of sugar cane in Sao Paulo state, Brazil, using two-phase sampling method. A double sampling with regression estimate was applied combining the information obtained from Landsat-MSS and aerial photographs. The estimates obtained by applying the technique were more precise than those estimates obtained from aerial photographs alone (Cappelletti *et al*, 1982).

Redondo *et al* (1984) tested the feasibility of using double sampling with a regression estimate to obtain the wheat hectarage in Buenos Aires, Argentina. They reported that, the accuracy achieved by applying the technique for wheat area estimation was good (Redondo *et al* (1984).

6.3. ADOPTED METHODOLOGY

To investigate the possibility of improving the crop type area estimates in the study area, Landsat-TM data were correlated with measurements obtained from a field survey. The resulted correlation coefficient was used in a regression estimator to predict crop areas when data from a Landsat-TM classified image is included in the calculation.

The two data sets (x and y) which are used in the regression analysis were obtained on a sample unit basis as follow :-

a. field area measurements (y) obtained by applying stratified random sampling strategy (see chapter 4), and

b. Landsat area measurements (x) based on the pixel count of classified TM image (see chapter 5).

One of the main reason for using the regression estimate is that its application is similar to the application of stratification, because both of these methods are applied in order to increase the precision and efficiency of a sample by making use of supplementary information about the population (Latham *et al* 1982).

One of the main questions posed by this study is whether the area estimate will be improved by taking Landsat-TM data into account or not. In other words, will the relative efficiency of the estimate be improved by combining both the field and satellite data? This in turn leads to other question, is the double sampling strategy (using a regression estimate) a proper sampling method for estimating the area of agricultural crops in County Durham?

The main reasons for combining both Landsat and field data are given in table 6.1. The table illustrates the main differences between both field and Landsat surveys. Double sampling based on the combination of both surveys benefits from the advantages of both data sets. In other words, the Landsat data are capable of producing coarse measurements over a large area at a small cost per unit area; that field survey may give more accurate measurements but at large cost per unit area (Latham *et al*, 1982). These are the main reasons for combining the two data sets.

Table 6.1

A Comparison Between Field and Landsat Surveys

	Field Survey	Landsat Survey
Coverage	Small areas	Large areas
Timeliness	Less timely	Can be implemented in a more timely fashion
Cost	High on a per unit area	Less costly on a per unit area
Bias	Low bias if implemented with appropriate safeguard	High
Imprecision	High	Low

6.4. STATISTICAL METHODOLOGY

This section describes the statistical methods used for estimating the parameters for relating field and satellite data. The discussion and results are explained in detail in the section 6.5. The calculations of regression estimates were developed according to the procedures used by USDA (Hanuschak et al 1979 ; Cook et al 1984 ; Hanuschak et al 1982); Latham et al (1982) in Gefara Plain, Libya ; Hafner *et al* (1982) in Yemen ; and by Angelis and Gizzi (1984) in Italy.

A correlation analysis was performed between crop type area estimates determined by both Landsat TM and field survey data. Then the coefficient of determination (r^2) which shows the level of the agreement between the Landsat-TM and field area measurements (ha) for the crop type in each stratum was calculated from the equation

$$r_{xy}^2 = \frac{\sum_{i=1}^{n}(y_i - \bar{y})(x_i - \bar{x})}{\sum_{i=1}^{n}(y_i - \bar{y})^2 \sum_{i=1}^{n}(x_i - \bar{x})^2} \qquad 6.8$$

where x is the area measurement (ha) obtained from the Landsat-TM classification, and y is the area measurement (ha) obtained from the field survey. The regression estimate was calculated from the linear equation,

$$\bar{y}_{h_{reg}} = \bar{y}_h + b_h(\bar{X}_h - \bar{x}_h) \qquad 6.9$$

with variance of

$$Var(\bar{y}_{h_{reg}}) = N(N-n)\frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n(n-1)}(1 - r_{xy}^2) \qquad 6.10$$

and standard deviation of

$$s(\bar{y}_{h_{reg}}) = \sqrt{N(N-n)\frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n(n-1)}(1 - r_{xy}^2)} \qquad 6.11$$

where

N_h = the total number of sampling units in stratum h,

$\bar{y}_h$= the field sample average crop area measurement (ha) in the stratum,

$\bar{x}_h$= the average sample classified crop pixels for the stratum, sample classified pixels divided by the sample units,

$\bar{X}_h$=the average classified crop pixels for the stratum h , total classified pixels divided by total units in the stratum,

and b_h=the slope of the regression curve $(y = a + bx)$ between field (dependent) and Landsat (independent) data. This was calculated from the equation

$$b_h = \frac{\sum_{i=1}^{n}(y_i - \bar{y})(x_i - \bar{x})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad 6.12$$

The stratum total for $\widehat{y}_{h_{reg}}$ is estimated by multiplying the total number of possible sample units in the stratum, N_h, thus

$$\widehat{y}_{h_{reg}} = N_h[\bar{y}_h + b_h(\bar{X}_h - \bar{x}_h)] \quad 6.13$$

with variance of

$$Var(\widehat{y}_{h_{reg}}) = N_h^2(\frac{s_h^2}{n_h})(1 - r_{xy}^2) \quad 6.14$$

or

$$Var(\widehat{y}_{h_{reg}}) = N_h^2[Var(\bar{y}_{h_{reg}})] \quad 6.15$$

and standard error

$$SE(\widehat{y}_{h_{reg}}) = \sqrt{N_h^2[Var(\bar{y}_{h_{reg}})]} \quad 6.16$$

$$s(\widehat{y}_{h_{reg}}) = N_h[SE(\bar{y}_{h_{reg}})] \quad 6.17$$

To express the variance or the standard error of the estimate as a percentage of the population value ($\widehat{Y}_{h_{reg}}$), the coefficient of variation ($C.V$) was defined as

$$CV_h = \sqrt{\frac{Var(\bar{y}_{h_{reg}})N^2}{N_h^2[\bar{y}_{h_{reg}}]}} \times 100 \qquad 6.18$$

this is equal to

$$\frac{N[SE(\bar{y}_{h_{reg}})]}{N_h \bar{y}_{h_{reg}}} \times 100 \qquad 6.19$$

Also it can be written as

$$CV_h = \frac{SE(\bar{y}_{h_{reg}})}{\bar{y}_{h_{reg}}} \times 100 \qquad 6.20$$

For the overall strata, the mean was calculated by

$$\bar{Y}_{reg} = \frac{1}{N} \sum_{h=1}^{5} N_h \bar{y}_{h_{reg}} \qquad 6.21$$

with variance

$$Var(\bar{y}_{reg}) = \frac{1}{N^2} \sum_{h=1}^{5} N^2 (\frac{s_h^2}{n_h})(1 - r_{xy}^2) \qquad 6.22$$

and standard error

$$SE(\bar{y}_{reg}) = \sqrt{\frac{1}{N^2} \sum_{h=1}^{5} N^2 (\frac{s_h^2}{n_h})(1 - r_{xy}^2)} \qquad 6.23$$

and the crop type area estimation by regression in the whole study area is,

$$\widehat{Y}_{reg} = \sum_{h=1}^{5} N_h \bar{Y}_{h_{reg}} \qquad 6.24$$

with variance

$$Var(\widehat{Y}_{reg}) = \sum_{h=1}^{5} N_h^2 (\frac{s_h^2}{n_h})(1 - r_{xy}^2) \qquad 6.25$$

and standard error

$$SE(\widehat{Y}_{reg}) = \sum_{h=1}^{5} \sqrt{N_h^2 (\frac{s_h^2}{n_h})(1 - r_{xy}^2)} \qquad 6.26$$

6.5. Results and Discussion

This section will illustrate the results of applying the double sampling technique using the linear regression estimator. Also, a discussion about the implementation of the the statistical methodology mentioned in section 6.4 will be presented.

All 44 sample units evaluated for the field estimation (see chapter 4), were compared with the corresponding area obtained from classification of Landsat imagery. After the field visit to each sample unit took place, where necessary new field boundaries were noted and the area of each land-cover type (y) was measured on the aerial photograph. Each SU was transferred to the image using the national grid coordinates obtained from 1:50,000 OS maps. Once the image was classified (see chapter 5), the number of pixels (x) in each class was calculated for each sample unit.

The coefficient of determination (r^2) for each category was computed from equation 6.8. Using the information obtained from the correlation analysis between the the Landsat and field data, a regression curve ($y = a + bx$) was drawn. In the regression analysis the field data represented the dependent variable (y) and the Landsat TM the independent variable (x). Figures 6.1 to 6.192 show the regression curves between the two measurements for each crop type in all strata.

Figure 6.2 **The Linear Regression for Field and Landsat Area Measurements of Oilseed Rape in Stratum One**

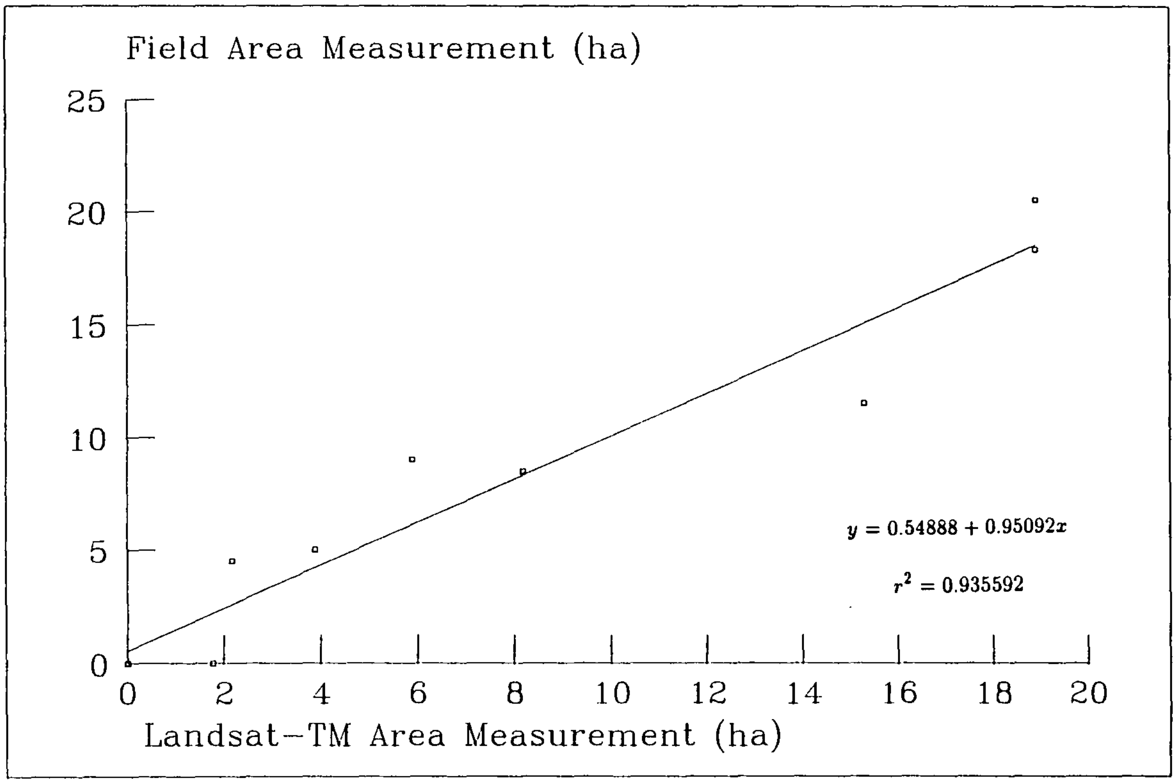


Figure 6.3 **The Linear Regression for Field and Landsat Area Measurements of Oilseed Rape in Stratum Two**

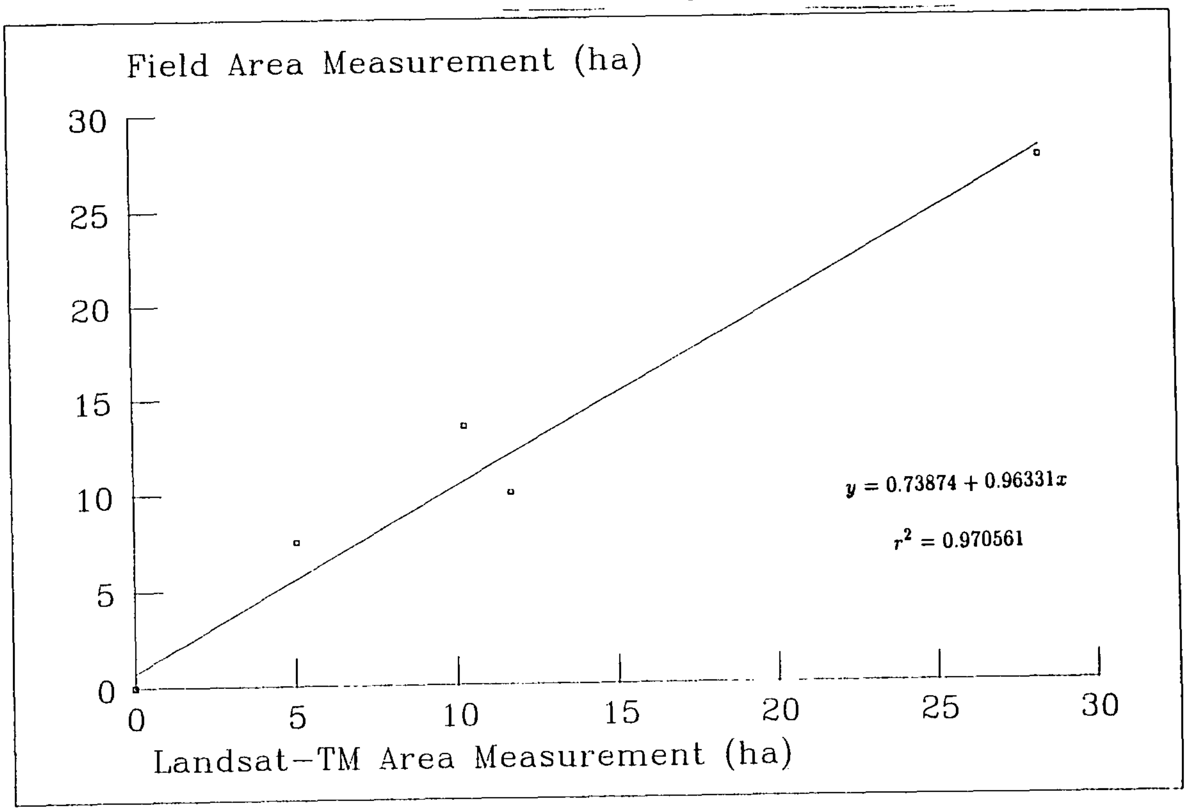


Figure 6.4 The Linear Regression for Field and Landsat Area Measurements of Oilseed Rape in Stratum Three

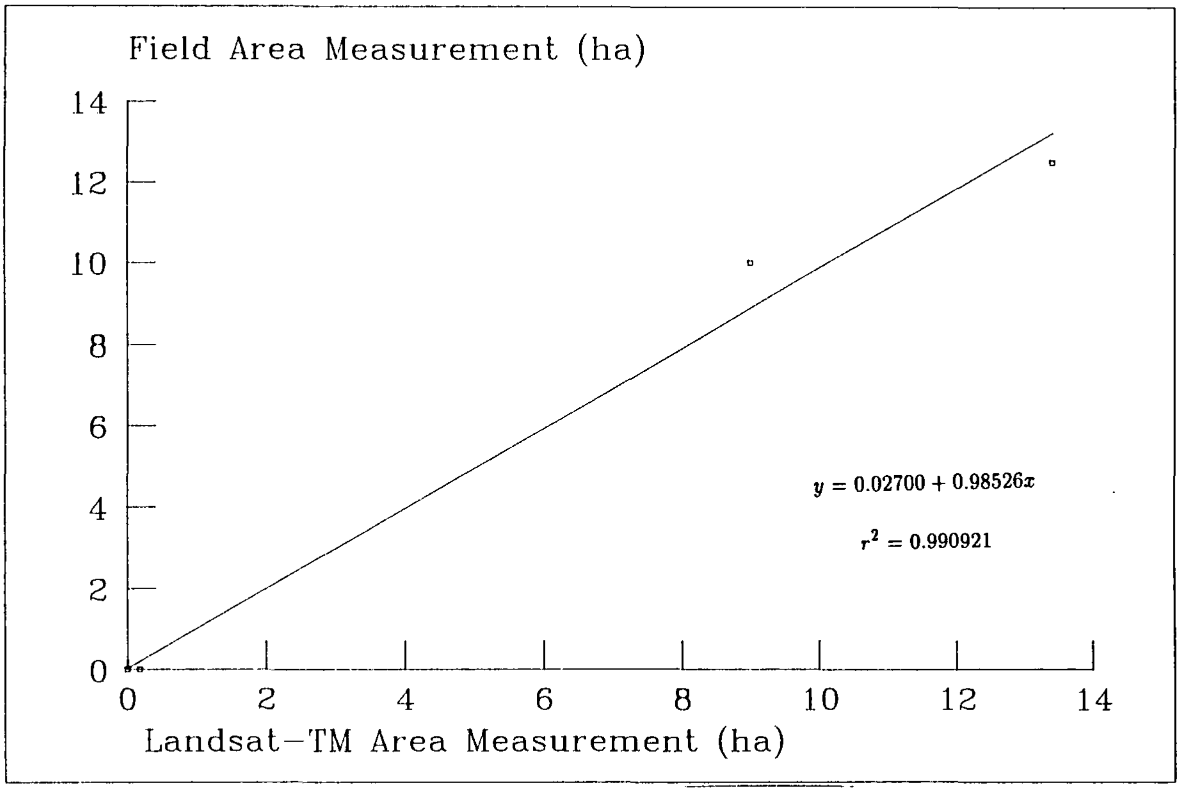


Figure 6.5 The Linear Regression for Field and Landsat Area Measurements of Winter Wheat in Stratum One

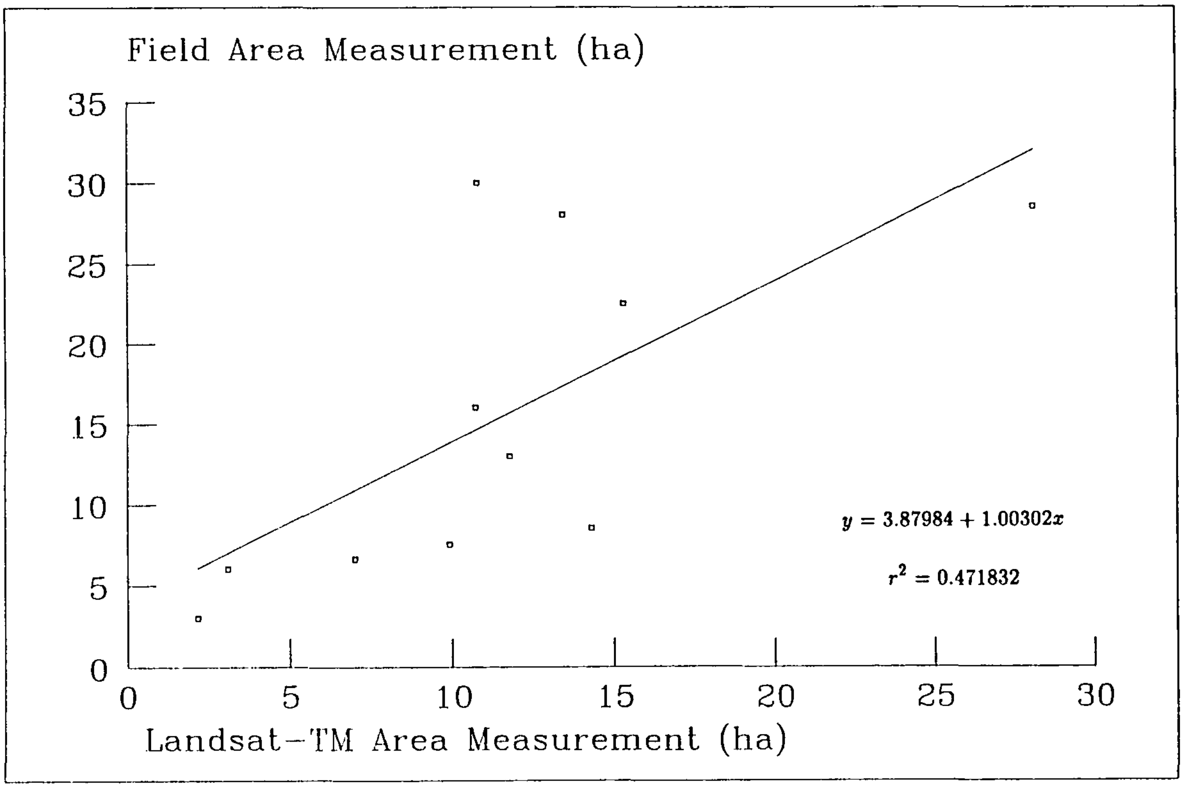


Figure 6.6 **The Linear Regression for Field and Landsat Area Measurements of Winter Wheat in Stratum Two**

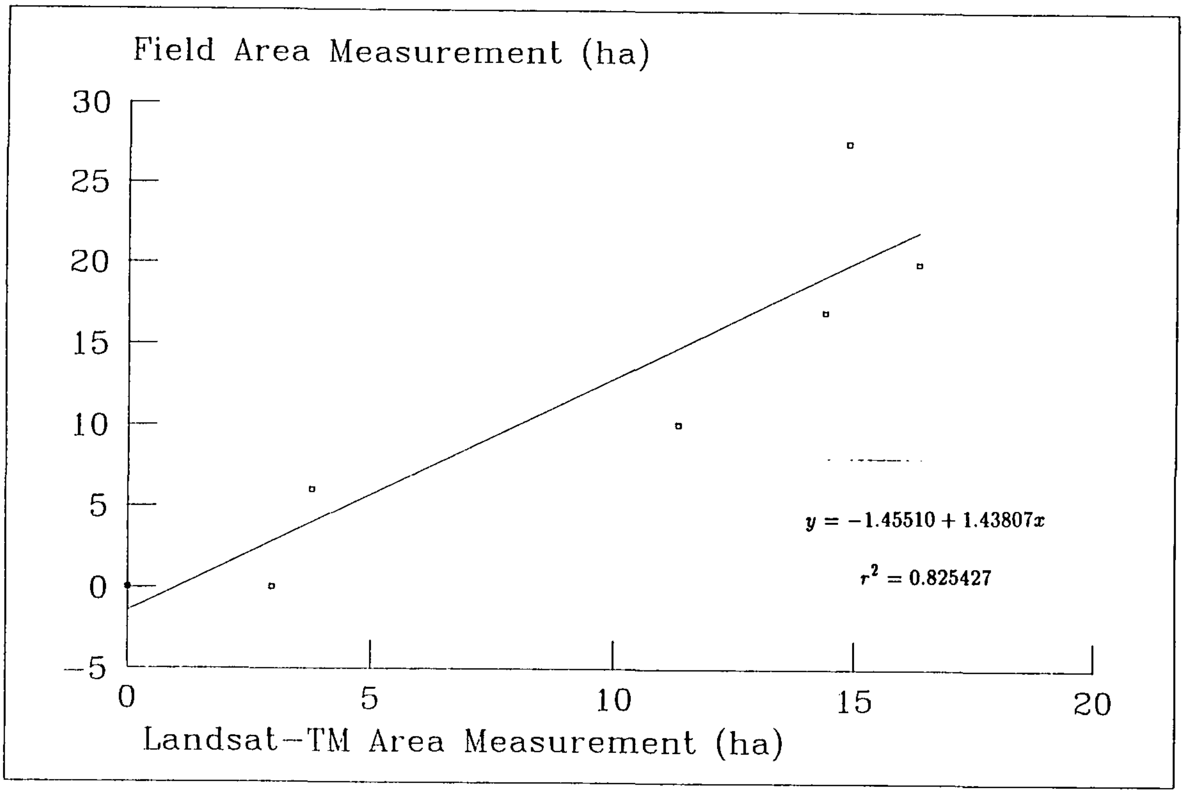


Figure 6.7 **The Linear Regression for Field and Landsat Area Measurements of Winter Wheat in Stratum Three**

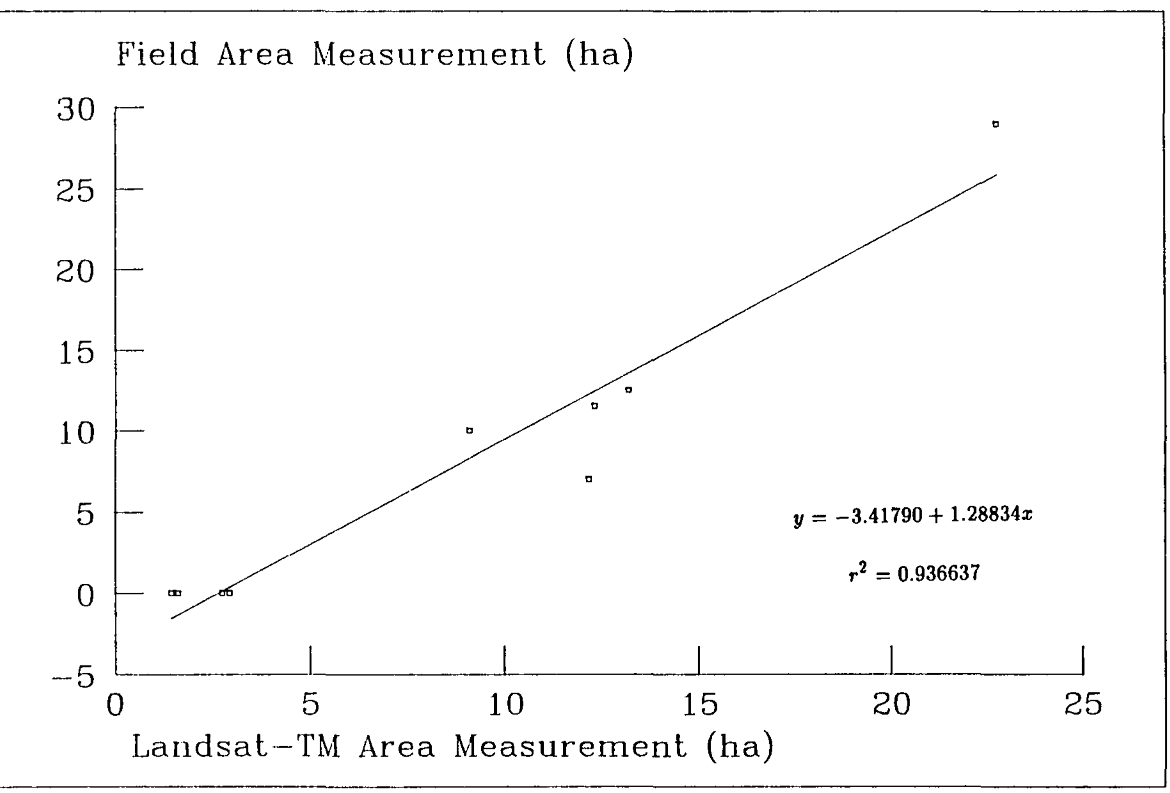


Figure 6.8 **The Linear Regression for Field and Landsat Area Measurements of Winter Wheat in Stratum Four**

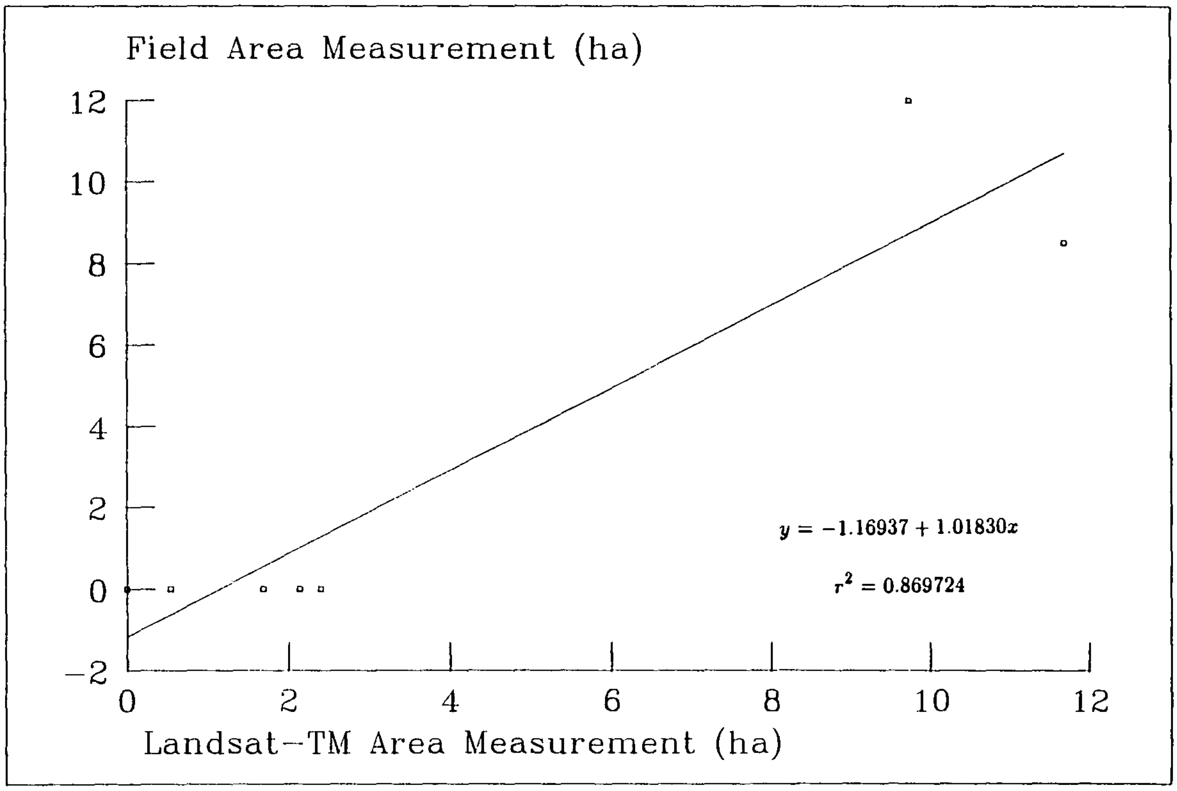


Figure 6.9 **The Linear Regression for Field and Landsat Area Measurements of Winter Wheat in Stratum Five**

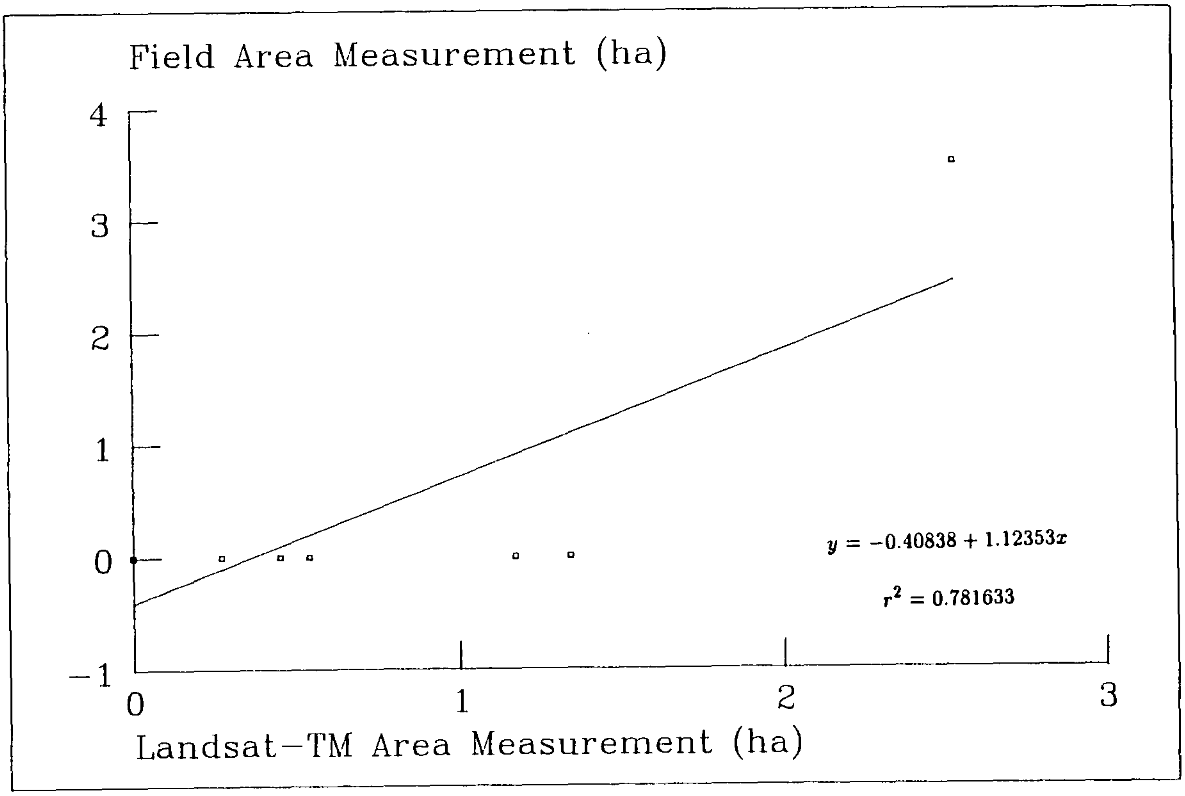


Figure 6.10 The Linear Regression for Field and Landsat Area Measurements of Winter Barley in Stratum One

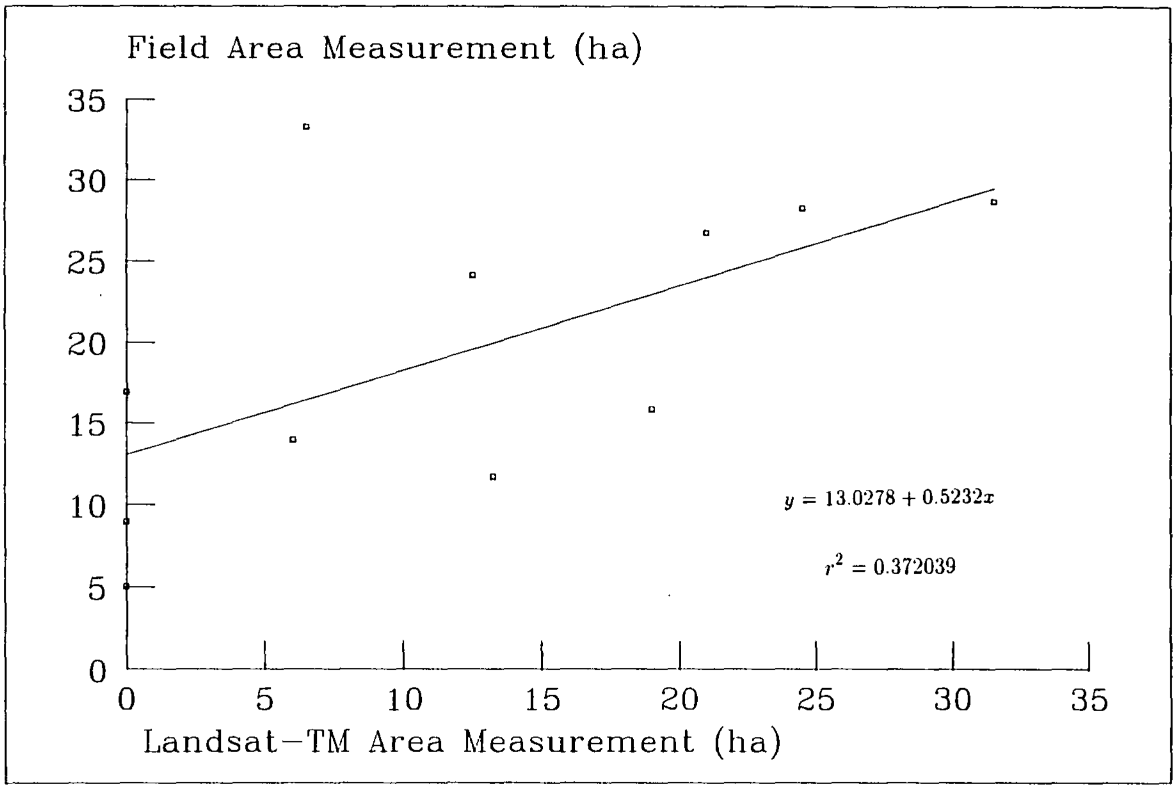


Figure 6.11 The Linear Regression for Field and Landsat Area Measurements of Winter Barley in Stratum Two

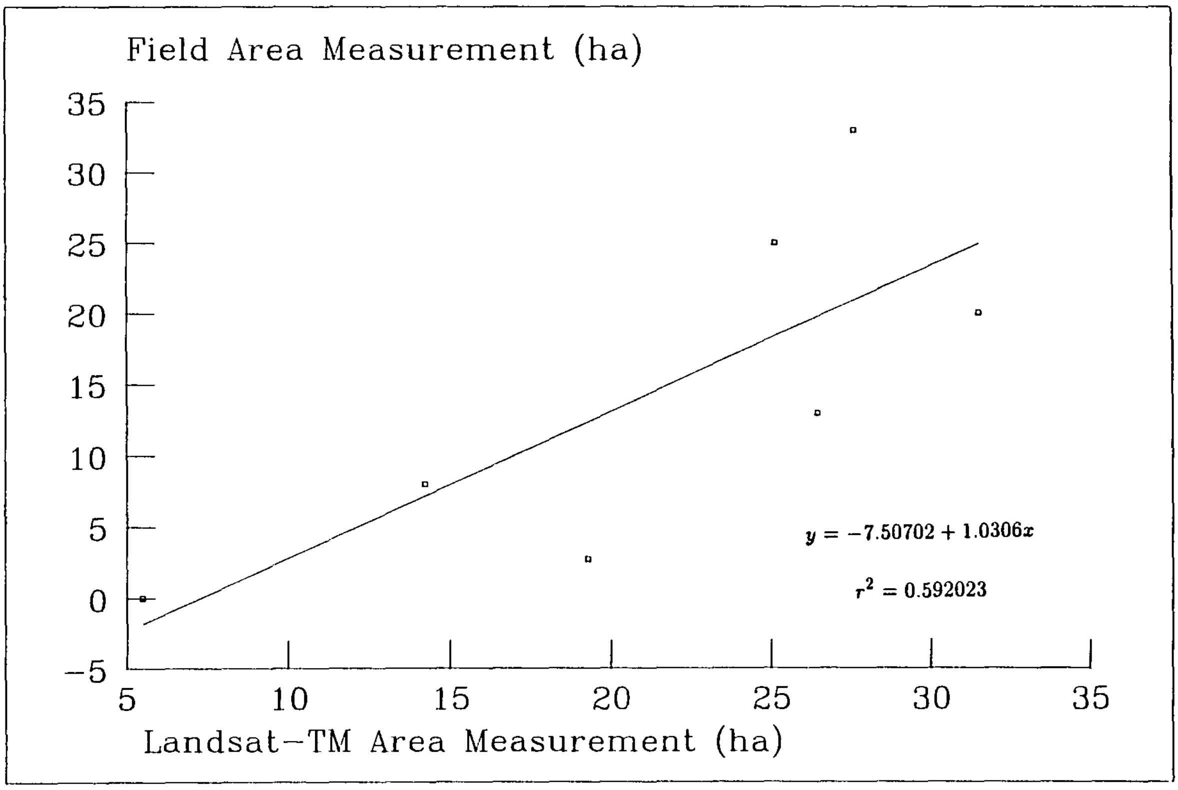


Figure 6.12 The Linear Regression for Field and Landsat Area Measurements of Winter Barley in Stratum Three

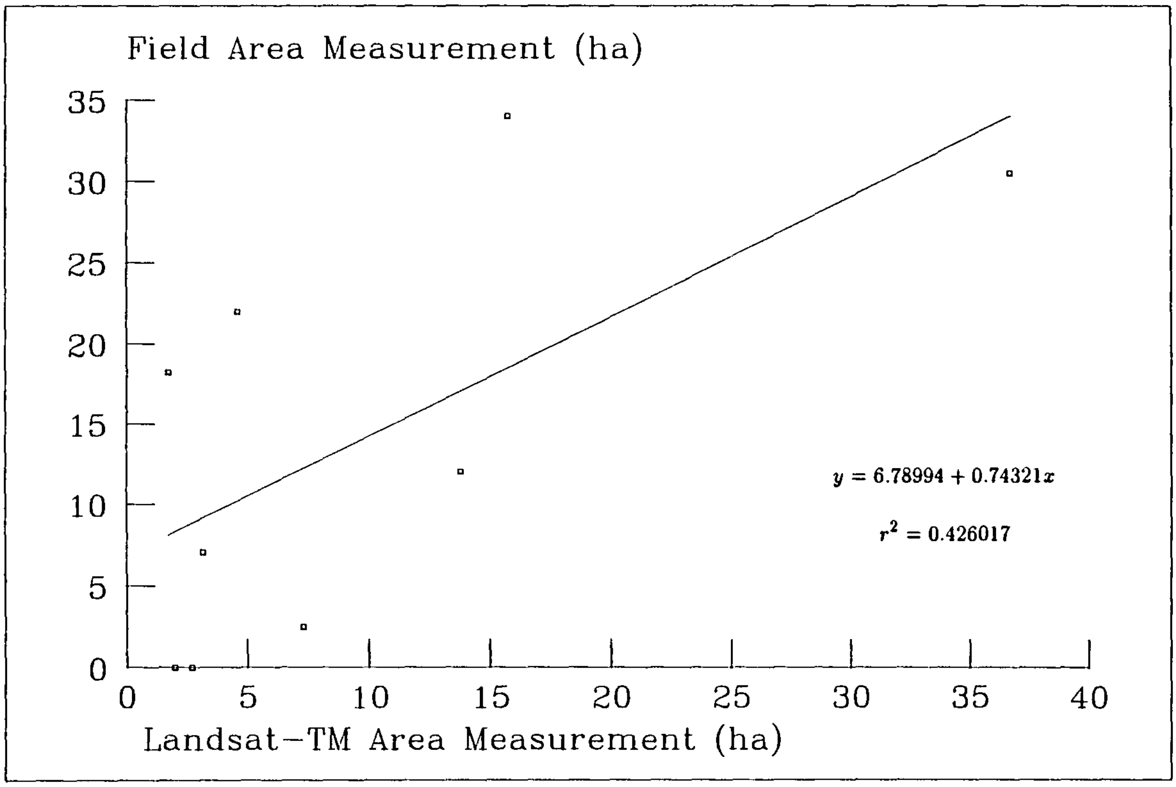


Figure 6.13 The Linear Regression for Field and Landsat Area Measurements of Winter Barley in Stratum Four

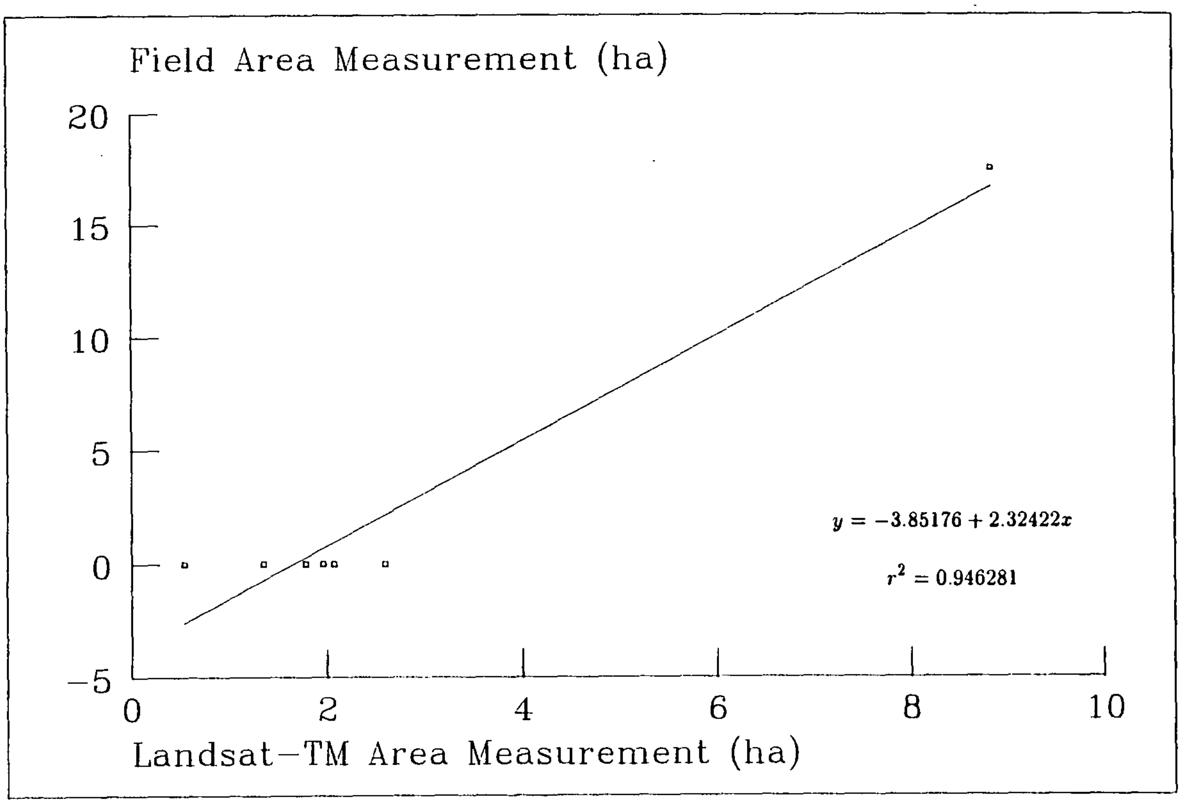


Figure 6.14 **The Linear Regression for Field and Landsat Area Measurements of Winter Barley in Stratum Five**

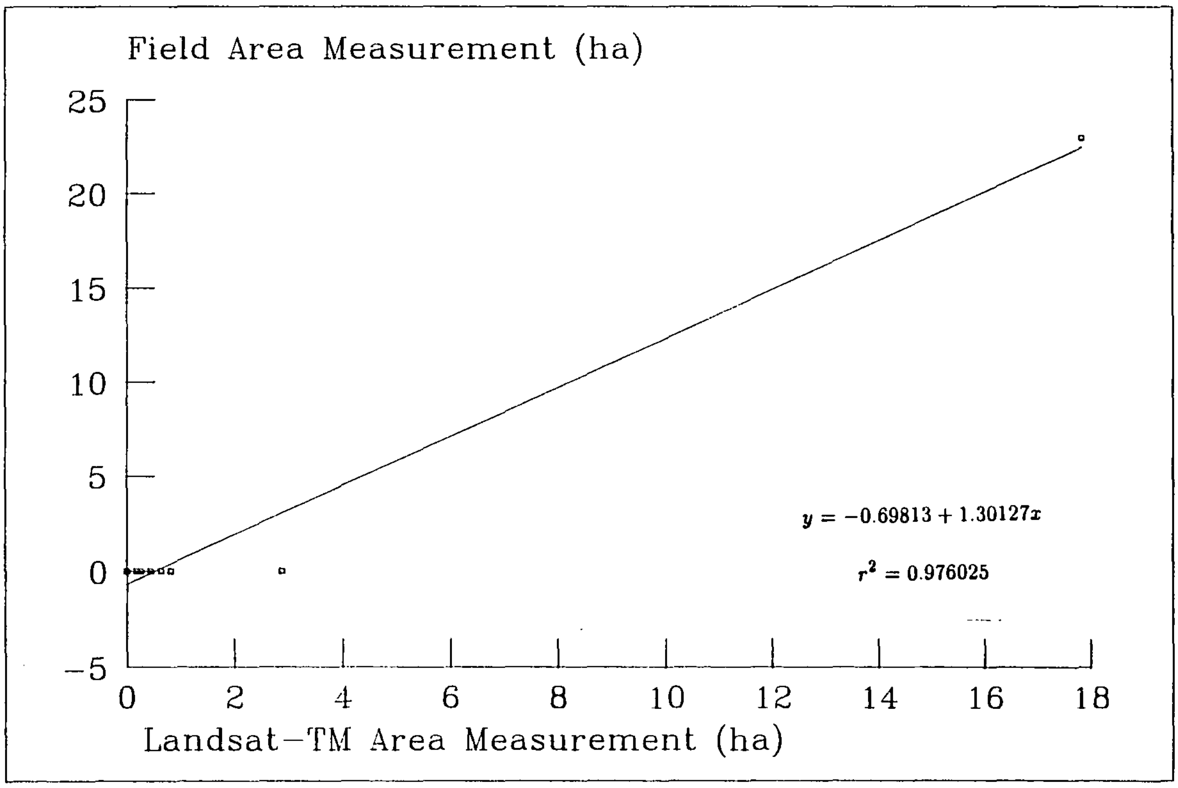


Figure 6.15 **The Linear Regression for Field and Landsat Area Measurements of Pastures in Stratum One**

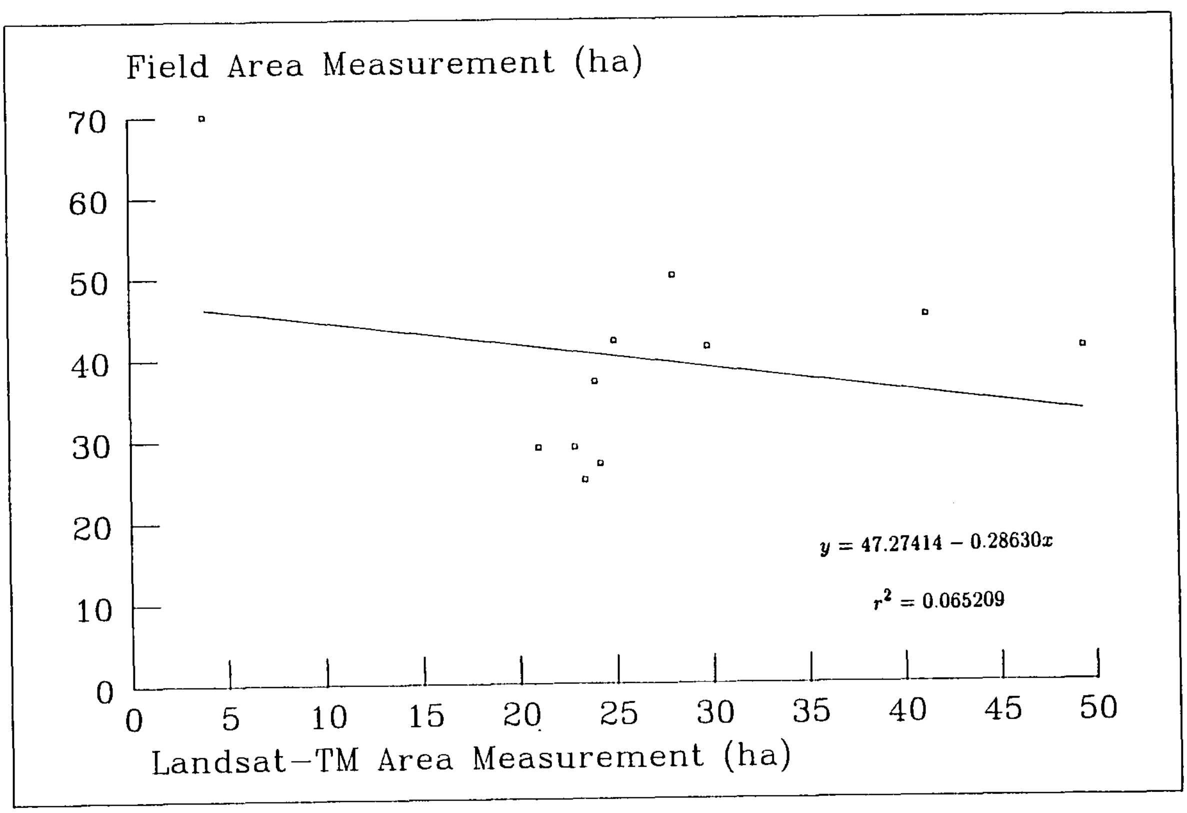


Figure 6.16 The Linear Regression for Field and Landsat Area Measurements of Pastures in Stratum Two

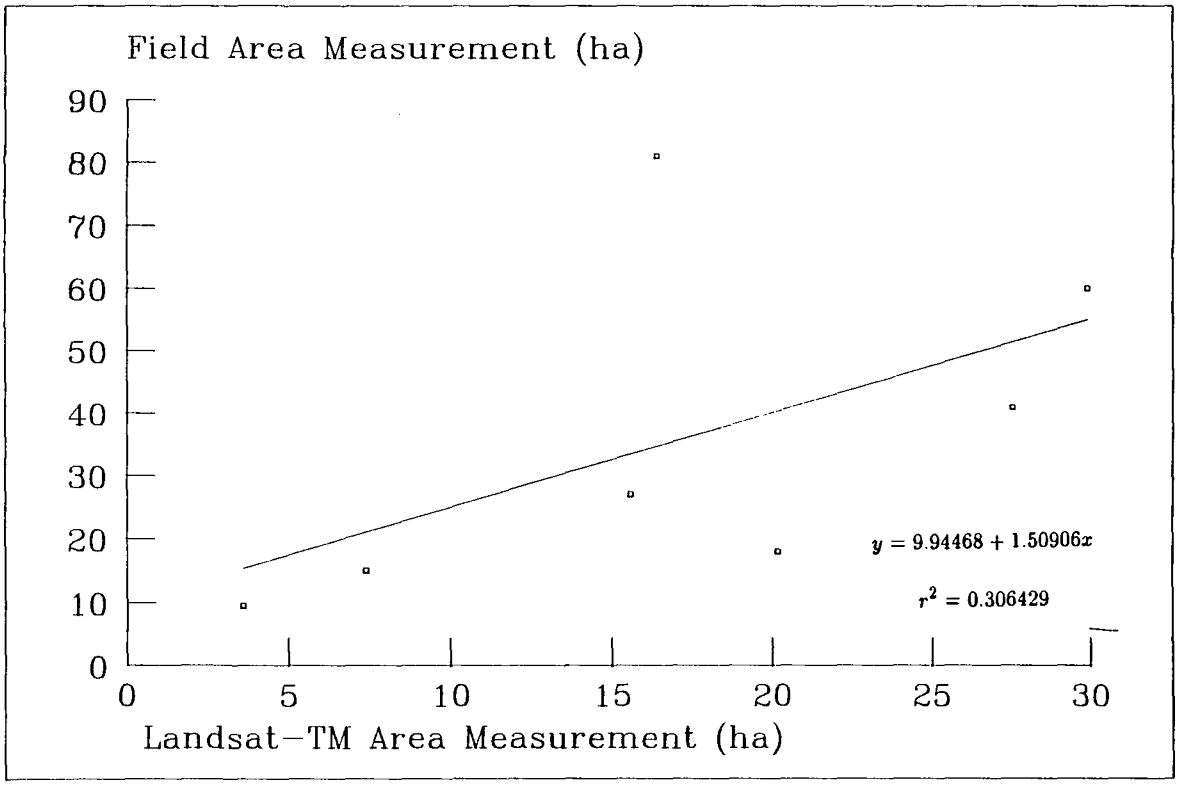


Figure 6.17 The Linear Regression for Field and Landsat Area Measurements of Pastures in Stratum Three

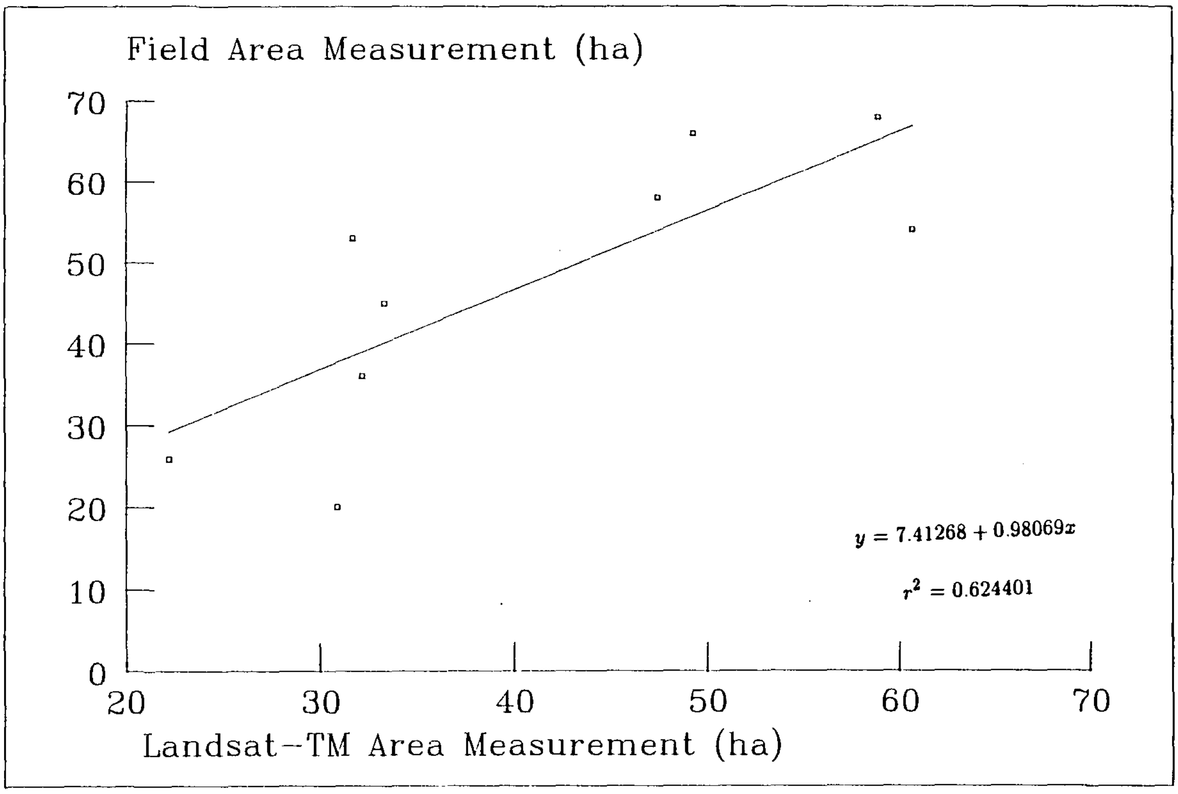


Figure 6.18 **The Linear Regression for Field and Landsat Area Measurements of Pastures in Stratum Four**

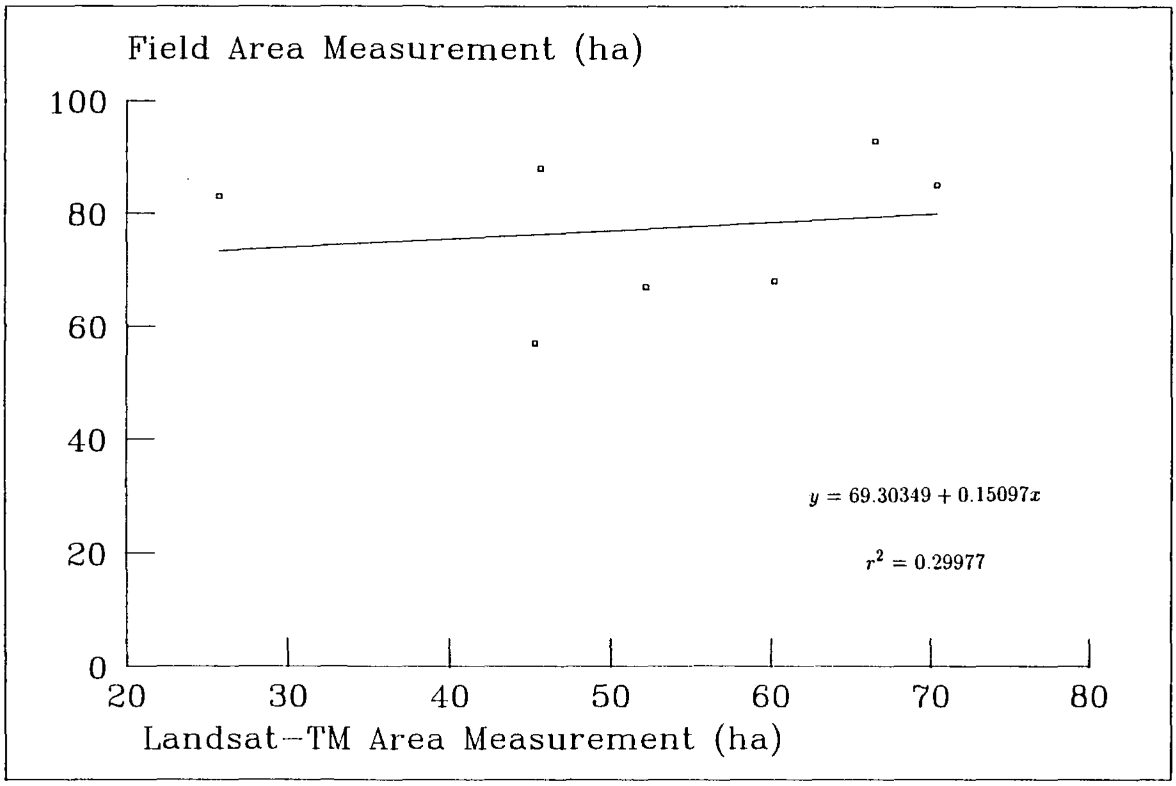


Figure 6.19 **The Linear Regression for Field and Landsat Area Measurements of Pastures in Stratum Five**

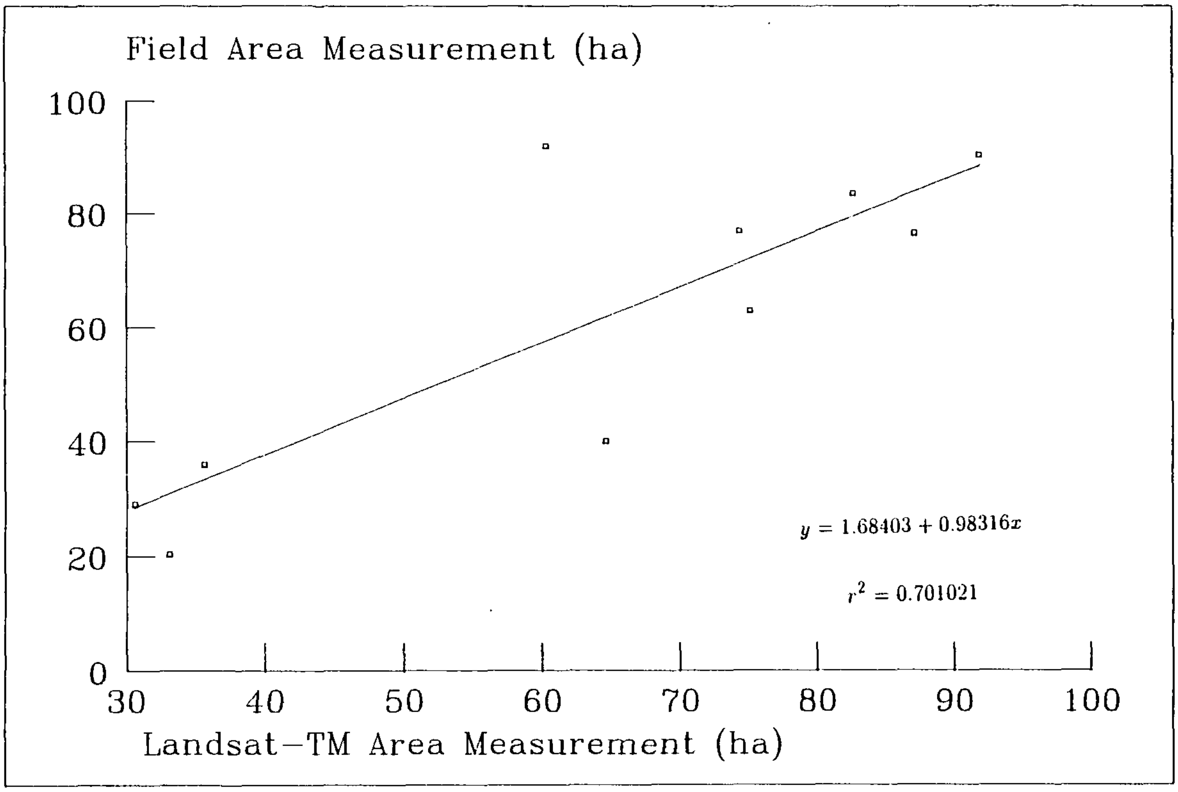


Table 6.2 illustrates the information needed to calculate the area estimates for oilseed rape in stratum one. The data in table 6.2 were plotted in a scatter plot in figure 6.20. As it is clear from the figure, all the points are close to the line $y = a + bx$, which gives a small value of $Var(\bar{y}_{h_{reg}})$. However, the large spread of points around the estimated line in figures 6.12 and 6.13 indicates that $Var(\bar{y}_{h_{reg}})$ can be relatively large due to the disagreement between both Landsat (x) and field (x) area measurements which in turn resulted in low correlation between both variables. The main reasons for this low correlation will be explained in detail later in this section.

Table 6.2

Data used for regression estimation of oilseed rape in stratum one

SU n	Field y_i	Landsat x_i	Deviation of x $y_i - \bar{y}$	Deviation of y $x_i - \bar{x}$	$(y_i - \bar{y})$ $(x_i - \bar{x})$	Squared Deviation of y $(y_i - \bar{y})^2$	Squared Deviation of x $(x_i - \bar{x})^2$
1	11.5	15.28	4.473	8.467	37.8729	20.001	71.695
2	0.0	0.0	-7.0273	-6.8127	47.8749	49.383	46.413
3	9.0	5.89	1.973	-0.9227	-1.8205	3.893	0.8514
4	4.5	2.16	-2.527	-4.653	11.7581	6.386	21.648
5	20.5	18.9	13.473	12.087	162.8482	181.522	146.103
6	5.0	3.87	-2.027	-2.943	5.9655	4.109	8.659
7	0.0	0.0	-7.0273	-6.8127	47.8749	49.383	46.413
8	0.0	0.0	-7.0273	-6.8127	47.8749	49.383	46.413
9	8.5	8.19	1.4727	1.377	2.0279	2.169	1.897
10	18.3	18.89	11.272	12.077	136.1319	127.074	145.861
11	0.0	1.76	-7.0273	-5.053	35.5089	49.383	25.530
Sums	77.3 $\sum y$	74.94 $\sum x$	0.0	0.0	533.9176	542.686 $\sum(y_i - \bar{y})^2$	561.500 $\sum(x_i - \bar{y})^2$

The results obtained show that the oilseed rape has the highest coefficient of determination. As mentioned in section 4.7.3, the crop in this time of the year is in flowering stage, which allows it to be clearly identified by the Landsat-TM sensor in all bands. Specifically the yellow colour of the crop gives no confusion between it and any other crop in the study area. The only source of error in this case is misleading information given by the farmers, they may have accidentally given wrong information about some oilseed rape fields. For example, they may say that the field was planted to winter wheat or grass, but in fact it was oilseed rape or *vice versa*.

When the linear regression model was applied for the pasture category, the coefficient of determination (r^2) was very low. For instance, r^2 of the pasture in stratum one, has scored only 0.065. The main reason for this low figure is the low correlation between both Landsat and field area measurements. To assess the causes of this low correlation, the data for pasture in stratum one were analysed further.

When the regression analysis was carried for the data of pasture category in stratum one (see figure 6.15), it was noticed that there are some points which do not lie close to the regression line. These points were marked on figure 6.20 as A, B, and C. To assess the effect of these outliers on the regression estimation, the coefficient of determination was calculated for all the points excluding points A, B, and C. The r^2 obtained after excluding the outliers dramatically increased to 0.556. This indicates that the outliers have a very strong effect on the linear regression model calculation for pasture in stratum one. Moreover, to emphasise this effect, the linear regression equation for all the points was obtained and compared with the regression equation produced by using only the outliers. For all 11 points, the linear regression equation was

$$y = 47.3 - 0.286x$$

while for the outliers it only was

$$y = 72.4 - 0.647x$$

Because the regression estimation for pasture in stratum one is affected by outliers, further analysis was carried out. As it is clear from the scatter plot in figure 6.20, the x and y for points A, B, and C have not the same values. In other words, the field area measurements (ha) for sample units A, B, and C in stratum one are greater than those measured from Landsat-TM.

The same situation occurred when the linear regression model was applied to the pasture class in stratum two. Figure 6.21 shows that the area measurements obtained by the field survey were again greater than those measurements recorded by Landsat-TM for point D. When the data obtained from sample unit D were excluded from the regression analysis, the coefficient of determination (r^2) of the stratum was increased from 0.554 to 0.886. Hence outlier D had a strong effect on the regression calculation for pasture in stratum two.

Figure 6.20

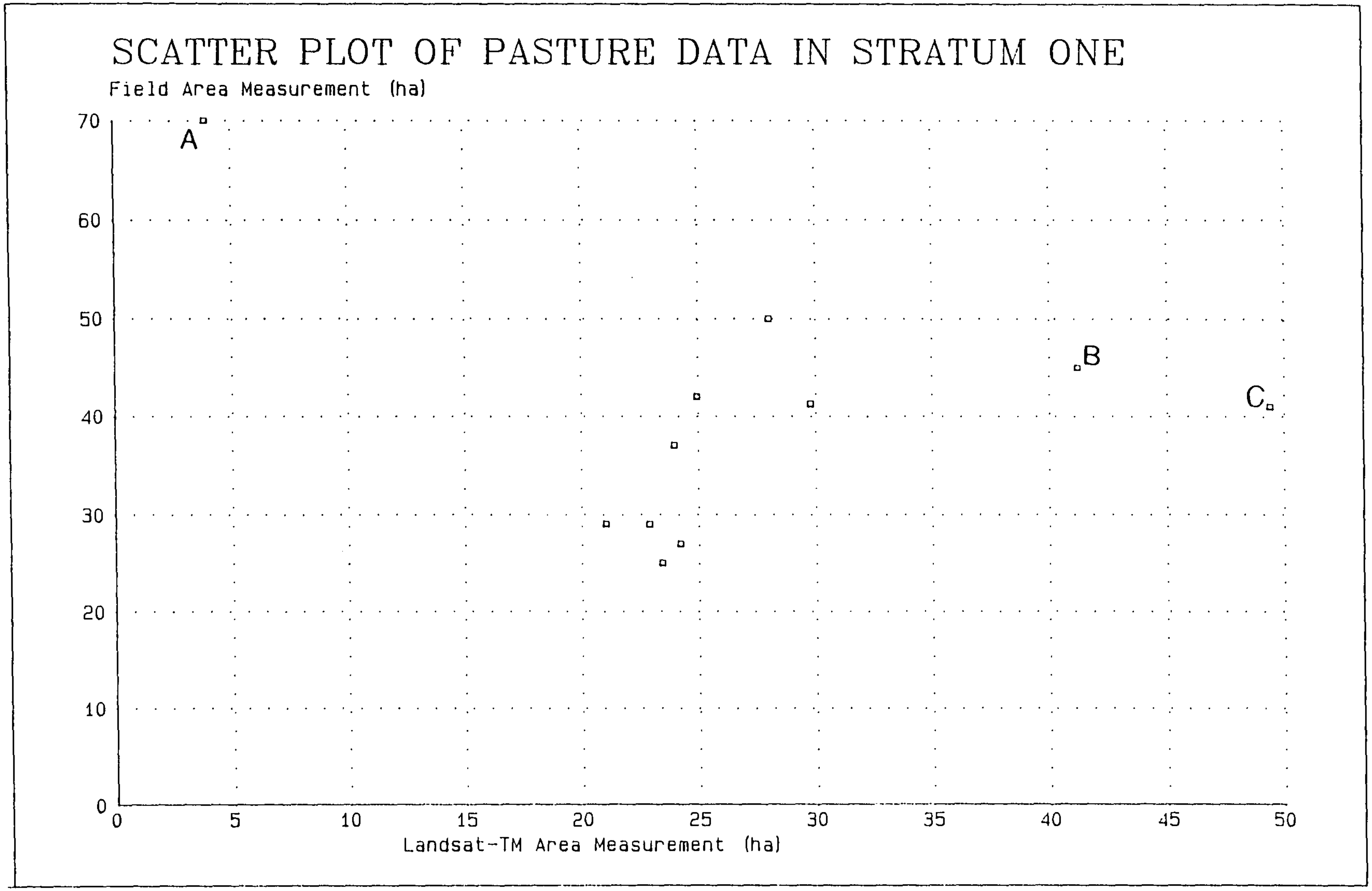
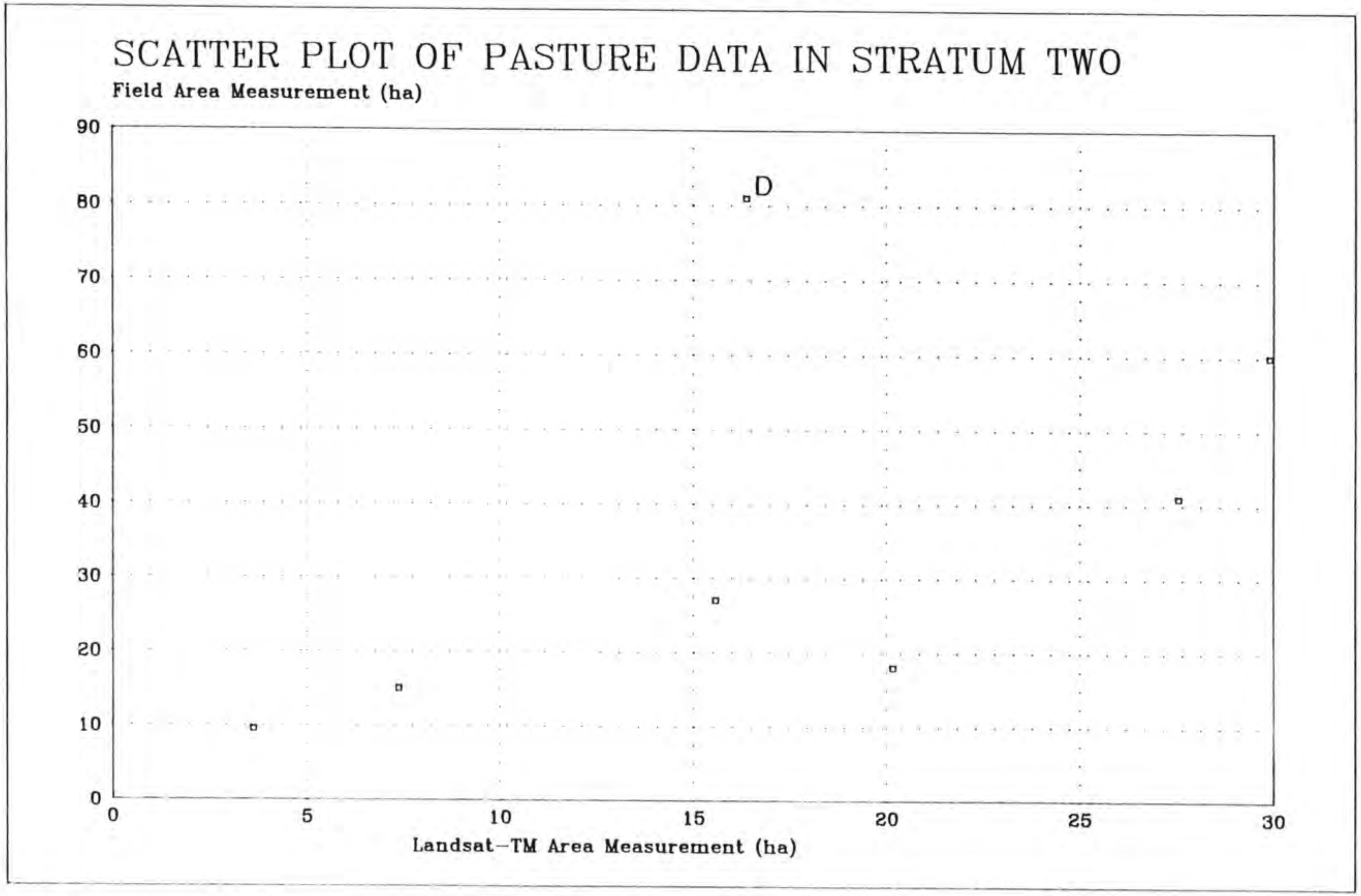
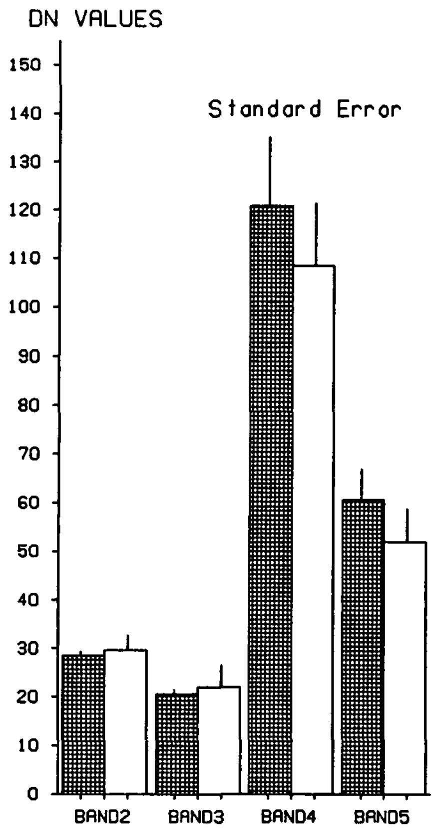

SCATTER PLOT OF PASTURE DATA IN STRATUM ONE
Field Area Measurement (ha)
70
60
50
40
30
20
10
0
A
B
C
0
5
10
15
20
25
30
35
40
45
50
Landsat-TM Area Measurement (ha)

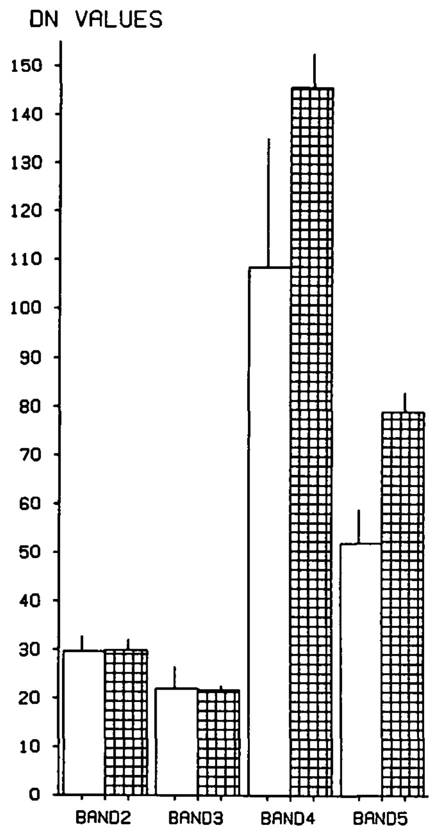
Figure **6.21**

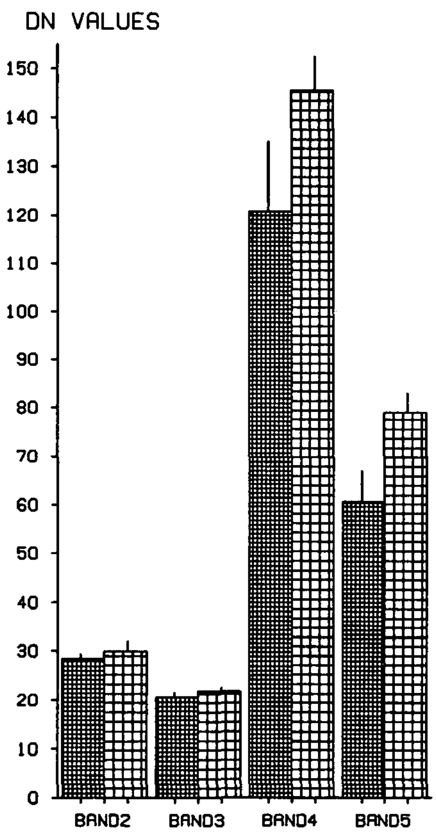

SCATTER PLOT OF PASTURE DATA IN STRATUM TWO
Field Area Measurement (ha)
90
80
70
60
50
40
30
20
10
0
D
0
5
10
15
20
25
30
Landsat-TM Area Measurement (ha)

The large difference between the area measurements obtained by Landsat and the field survey may be explained in several ways. First, the farmers may not have distinguished between grass and cut grass in the questionnaire survey for the time when the Landsat sensed the study area. The main reason being the long time interval between the acquisition of the Landsat data and the time of the interview. For some farmers three years previously was a long time to remember if the field was cut or not. The second reason for the low (r^2) for pasture class, is that the farmers found it easier to answer grass, if they did not remember what was in the field in that time. Also, there was confusion between managed grass and winter cereals (see section 5.3.5). As is shown later, this confusion was also a reason for low r^2 values for winter wheat and winter barley.

In the case of the winter wheat and winter barley categories, the low coefficient of determination value can be explained by the nature of the spectral similarity between both crops. The errors are partly due to the difficulties in discriminating between the two classes. The spectral response of these crops is shown in selected TM bands and illustrated in figure 6.22. This similarity has caused a confusion between the two crops when the likelihood classifier was applied to the Landsat-TM data. As a result of this spectral confusion, the Landsat area measurements obtained varied from those measurements recorded by the field survey. This variation between the two measurements has resulted in low coefficients of determination.







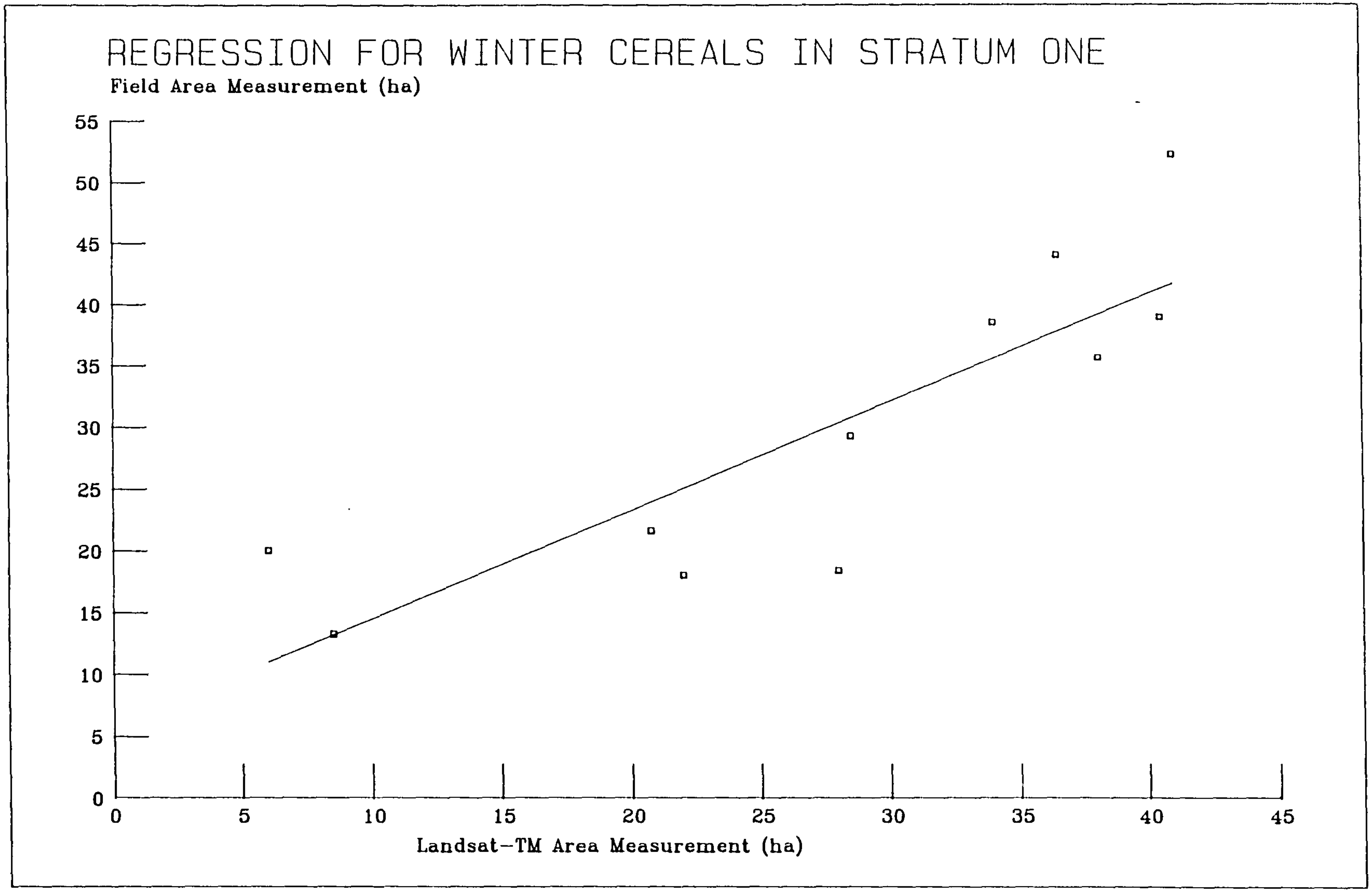
MANAGED PASTURES
WINTER BARLEY
WINTER WHEAT

Fig. (6.22) Plot of DN Values for Winter Wheat, Winter Barley and Managed Pastures for TM Bands (data represent means ±SD).The data represent of different training sites obtained from different strata over the study area

Also, difficulties arose with the spectral separability of winter cereals and managed pasture as shown in figure 6.22. The coefficient of determination can be increased by combining both winter wheat and winter barley as a winter cereals category. As illustrated in figure 6.23, the variation between the two measurements was reduced when both winter wheat and winter barley were treated as one category. The r^2 was increased from 0.4718 and 0.372 for both winter wheat and winter barley respectively, to 0.817 for winter cereals. Despite this dramatic increase in the coefficient of determination of winter cereals, it is still not very high. The main difficulty was the accuracy of the information given by the farmers. The question 'what was in the field'? was answered as cereal by some farmers rather than giving a specific crop type. Because they do not keep records on their farms, it was difficult for the farmers to remember which type of cereals the field was planted.

The statistical methodology illustrated in section 6.4 was applied for each stratum and the results were aggregated for the whole study area to calculate the total crop type area estimation using the regression estimator. The r^2 obtained from the correlation analysis were used in the regression analysis. Tables 6.3 to 6.6 give detailed results of the regression estimate calculation from the application of equations 6.9. Also, the variance and standard error of the regression estimate were calculated using equations 6.16 and 6.17.

Figure 6.23



REGRESSION FOR WINTER CEREALS IN STRATUM ONE
Field Area Measurement (ha)
55
50
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
45
Landsat-TM Area Measurement (ha)

Table 6.3

Regression area estimates (ha) of oilseed rape for total study area

Stratum (h)	$\bar{y}_h$	$\bar{x}_h$	$\sum(y-\bar{y})^2$	$\sum(x-\bar{x})^2$	s_h^2	N_h	$\bar{X}_h$	r_{xy}	b_h	$\hat{y}_{h_{reg}}$	$SE(\hat{y}_{h_{reg}})$
1	7.0273	6.8127	542.686	561.500	54.2682	359	5.070	0.96726	0.95092	1928	199.2
2	8.3571	7.9086	605.867	633.669	100.976	244	8.61	0.98517	0.96331	2204	156.7
3	2.5000	2.5100	200.000	204.1596	25.0000	298	2.252	0.99545	0.98526	669.25	46.6
4	——	——	——	——	——	—-	——	——	——	——	——-
5	——	——	——	——	——	—-	——	——	——	——	——-

Table 6.4

Regression area estimates (ha) of winter wheat for total study area

Stratum (h)	$\bar{y}_h$	$\bar{x}_h$	$\sum(y-\bar{y})^2$	$\sum(x-\bar{x})^2$	s_h^2	N_h	$\bar{X}_h$	r_{xy}	b_h	$\hat{y}_{h_{reg}}$	$SE(\hat{y}_{h_{reg}})$
1	11.504	11.5036	1029.637	482.986	102.964	359	11.00	0.6869	1.00302	5364.6	785.9
2	11.514	9.1000	655.209	267.069	109.201	244	12.89	0.90853	1.43807	4142.9	396.8
3	7.7778	8.6900	734.056	414.231	91.757	298	10.17	0.96780	1.28834	2886.0	235.9
4	2.929	4.024	156.214	131.024	26.036	187	7.29	0.93259	1.01830	1169.5	127.7
5	0.35	0.675	11.025	5.778	1.225	327	0.41	0.88410	1.12353	17.10	52.7

Table 6.5

Regression area estimates (ha) of winter barley for total study area

Stratum (h)	$\bar{y}_h$	$\bar{x}_h$	$\sum(y-\bar{y})^2$	$\sum(x-\bar{x})^2$	s_h^2	N_h	$\bar{X}_h$	r_{xy}	b_h	$\hat{y}_{h_{reg}}$	$SE(\hat{y}_{h_{reg}})$
1	12.2045	19.4163	1166.108	852.167	116.610	359	15.65	0.6995	0.71102	3373.7	822.4
2	14.5286	21.3814	876.734	488.681	146.122	244	25.1	0.76943	1.03067	4480	701.8
3	14.0222	9.7311	1331.846	1026.667	166.392	298	9.25	0.6527	0.74321	4072.1	956
4	2.500	2.7329	262.500	45.9831	43.750	187	4.157	0.97277	2.32422	1086.6	106.3
5	2.300	2.304	476.100	274.423	52.90	327	2.01	0.98794	1.30127	625.83	114.7

Table 6.6

Regression area estimates (ha) of pasture for total study area

Stratum (h)	$\bar{y}_h$	$\bar{x}_h$	$\sum(y-\bar{y})^2$	$\sum(x-\bar{x})^2$	s_h^2	N_h	$\bar{X}_h$	r_{xy}	b_h	$\hat{y}_{h_{reg}}$	$SE(\hat{y}_{h_{reg}})$
1	69.659	27.5073	1675.289	1341.898	167.528	359	31.2	-0.25536	-0.2863	13858.1	13336
2	35.929	17.21865	4174.214	657.095	695.702	244	29.69	0.55356	1.50906	13357.2	1996.5
3	47.333	40.7067	2302.000	1494.528	287.750	298	57.43	0.79019	0.98069	18993.0	101.7
4	77.286	52.2771	1086.054	1390.855	176.238	187	117.6	0.17314	0.15097	16294.1	906.8
5	60.780	63.534	6583.756	4777.825	731.529	327	81.65	0.83727	0.98316	25699.0	1505.7

There are a number of things that can be seen from these formulae. First, the variance gets larger as the term $(\bar{X}_h - \bar{x}_h)$ gets larger; that is the variance gets quadratically larger the further $\bar{X}$ is from $\bar{x}$. This is to be expected because the further each point is evaluated from the location, $\bar{x}$, of the sample, the more variance we expect to have. This was the case in computing the variance for the pasture category. The reasons for the high variance is the low coefficient of determination between both Landsat TM and field measurements. The reasons for the low r^2 were mentioned earlier.

The coefficient of variation (CV) for all strata was calculated from equation 6.11. It was noticed that CV has decreased in all crops in the study area. For example, the CV for oil seed rape in stratum 3 was reduced from 66.7% to 6.7%. This shows how the regression estimator has successfully reduced the variance. The CV for winter wheat in strata 4 and 5, was reduced from 100% (see section 4.9) to 9.8% and 18.3%.

Table 6.7

A Comparison of field and regression area estimate of oilseed rape (ha) in County Durham

Stratum	Field Area Estimate			Regression Area Estimate		
h	Estimate	St. Error	$C.V$	Estimate	St. Error	$C.V$
1	2522.8	797.4	31.6	1928.1	199.2	10.3
2	2039.1	926.7	45.5	2204.0	156.7	7.1
3	745	496.7	66.7	669.2	46.6	6.7
4	—	—	—	—	—	—
5	—	—	—	—	—	—

Table 6.8

A Comparison of field and regression area estimate of winter wheat (ha) in County Durham

Stratum	Field Area Estimate			Regression Area Estimate		
h	Estimate	St. Error	$C.V$	Estimate	St. Error	$C.V$
1	5535.1	1098.3	19.8	5366	785.9	14.6
2	2809.5	963.7	34.3	4143.2	396.8	9.6
3	2317.8	951.5	41.1	2884	235.9	8.2
4	5476.6	360.6	6.6	1169.5	127.7	10.9
5	114.5	114.5	100	17.1	52.7	308.2

Table 6.9

A Comparison of field and regression area estimate of winter barley (ha) in County Durham

Stratum	Field Area Estimate			Regression Area Estimate		
h	Estimate	St. error	$C.V$	Estimate	St. error	$C.V$
1	4381.4	1168.9	26.7	3374.1	822.4	24.4
2	3545	1114.8	31.4	4480	701.8	15.7
3	4178.6	1281.3	37.8	4072.1	956	23.5
4	467.5	467.5	100	1086.5	106.3	9.8
5	752.1	752.1	100	625.8	114.7	18.3

Table 6.10

A Comparison of field and regression area estimate of pasture (ha) in County Durham

Stratum	Field Area Estimate			Regression Area Estimate		
h	Estimate	St. error	$C.V$	Estimate	St. error	$C.V$
1	14237.6	1401	9.8	13857.7	1333.6	9.6
2	8766.6	2432.5	27.7	13357.3	1996.5	14.9
3	14105.3	1685	11.9	18992.1	1017	5.3
4	14452.4	938.3	6.5	16296.6	906.8	5.6
5	19875	2796.8	14.1	25699	1505.7	5.9

The final area estimate for each category using the regression estimate is shown in table 6.7 through 6.10 in each stratum. The standard deviation of the estimate was also computed and shown in the tables. The total area estimation for each crop type in the study area using regression estimator were calculated by using the equation 6.24.

Table 6.11

Area Estimates (ha) for Oilseed Rape

in County Durham, May 1985

Stratum	Field Area Estimate		Regression Area Estimate		RE	Landsat TM only
h	Estimate	St. Error	Estimate	St. Error		Estimate
1	2522.8	797.4	1928.1	199.2	15.6	1820.2
2	2039.1	926.7	2204.0	156.7	35	2100.8
3	745	496.7	669.2	46.6	113.6	671.1
4	—	—	—	—	—	—
5	—	—	—	—	—	—

Table 6.12

Area Estimates (ha) for Winter Wheat

in County Durham, May 1985

Stratum	Field Area Estimate		Regression Area Estimate		RE	Landsat TM only
h	Estimate	St. Error	Estimate	St. Error		Estimate
1	5535.1	1098.3	5366	785.9	2.0	3959.8
2	2809.5	963.7	4143.2	396.8	5.9	3145.6
3	2317.8	951.5	2884	235.9	16.3	3030.7
4	5476.6	360.6	1169.5	127.7	8.0	1363.2
5	114.5	114.5	17.1	52.7	4.7	134.1

Table 6.13

Area Estimates (ha) for Winter Barley

in County Durham, May 1985

Stratum	Field Area Estimate		Regression Area Estimate		*RE*	Landsat TM only
h	Estimate	St. Error	Estimate	St. Error		Estimate
1	4381.4	1168.9	3374.1	822.4	2.0	5617.6
2	3545	1114.8	4480	701.8	2.5	6124.4
3	4178.6	1281.3	4072.1	956	1.8	2756.5
4	467.5	467.5	1086.5	106.3-	19.3	777.4
5	752.1	752.1	625.8	114.7	43	657.3

Table 6.14

Area Estimates (ha) for Pasture

in County Durham, May 1985

Stratum	Field Area Estimate		Regression Area Estimate		*RE*	Landsat TM only
h	Estimate	St. Error	Estimate	St. Error		Estimate
1	14237.6	1401	13857.7	1333.6	1.1	11200.8
2	8766.6	2432.5	13357.3	1996.5	1.5	7244.4
3	14105.3	1685	18992.1	1017	2.7	17114.1
4	14452.4	938.3	16296.6	906.8	1.1	21991.2
5	19875	2796.8	25699	1505.7	3.5	26699.6

6.6. RELATIVE EFFICIENCY

In order to determine the success associated with applying the regression estimator, its relative efficiency RE is calculated (Hanuschak *et al* 1982). The relative efficiency is the ratio of the variances produced by two different sampling strategies to achieve a given level of precision. In this study the RE was computed by using the variance produced from both the field and double sampling area estimates. It is an important guide to examine whether the regression estimator has reduced the variance of the estimate by using double sampling approach.

The relative efficiency of the regression estimator based on Landsat and field measurements as compared with stratified random sample estimation based on only field data are shown in tables 6.11, 6.12, 6.13 and 6.14. The RE was calculated by the equation,

$$RE = \frac{Var(\bar{y}_{h_f})}{Var(\bar{y}_{h_{reg}}})\qquad 6.27$$

A gain in precision will be achieved if the RE value is greater than 1.0. However, a RE of less than 1.0 means that precision has been lost by using Landsat TM data. In this study, the RE was calculated as the ratio between the variance of the field area estimate and that variance produced as a result of applying the two-phase sampling approach. The relative efficiency of the different crop types of the study area are illustrated in table 6.15. The table shows that the REs for all categories are greater than 1.0 in all strata.

Looking at the RE figures, it can be seen that a gain in precision was achieved by using Landsat TM data in conjunction with the field data. This indicates the efficiency of the regression estimator applied by using the double sampling approach. In other words, the hybrid technique applied by combining both Landsat and field measurements has produced a more efficient estimate, than estimate obtained by field data only using stratified random sampling.

It is clear from the figures obtained by applying the statistical methods described in section 6.4, that the lower values of the relative efficiency are always accompanied by lower values of coefficient of determination for a particular crop type. This explains that the relative efficiency of a particular cover type depends largely on the value of the coefficient of determination for the Landsat and field data. In other words, the RE of a crop type was increased as the correlation between the Landsat-TM an field area measurements increased. Tables 6.15 illustrates the relationship between the relative efficiency and the coefficient of determination of the different crop type in the study area. For instance, in strata 1,2 and 4 the pasture category scored the lowest relative efficiency. The main reason for these low RE figures is that, those strata had a low correlation between the Landsat-TM and area measurements. The reasons for this low correlation were discussed in the section 6.5.

Oilseed rape gives the highest RE values which is expected given high value of coefficient of determination for this crop. This can be explained by looking at both RE and r^2 values for the oilseed rape in stratum 3.

It is concluded from this analysis that the regression estimator is always more efficient than the field estimator. Clearly, the regression estimator has reduced the imprecision in all strata but was more efficient in some strata than others. The maximum increase (113%) in relative efficiency by regression estimation for this study was obtained for oilseed rape in stratum 3.

The main conclusion which can be drawn from applying the statistical methodology is that if the correlation between the field area measurements (y) and the Landsat-TM area measurement (x), is sufficiently strong, significant reduction in the estimates' precision and bias can result when compared with single-phase sampling of (y) alone.

Table 6.15

The Coefficient of Determination (r^2) and Relative Efficiency Efficiency (RE) for Different Crop Type in the Study Area

Stratum	Oilseed rape		Winter wheat		Winter barley		Pastures	
h	r^2	RE	r^2	RE	r^2	RE	r^2	RE
1	0.936	15.6	0.4718	2.0	0.3720	2.0	0.0652	1.1
2	0.9706	35	0.8254	5.9	.5920	2.5	0.3064	1.5
3	0.9909	113.6	0.9366	16.3	0.4260	1.8	0.6244	2.7
4	——	——	0.8697	8.0	0.9462	19.3	0.02998	1.1
5	——	——	0.7816	4.7	0.9760	43	0.7010	3.5

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

The overall objective of the study was to develop and test techniques utilising satellite data for identification and determination of the aerial extent and distribution of agricultural crops over County Durham. Specifically the objectives can be summarised as follows :-

- to test the role of satellite data for discrimination between different crops over County Durham,

- to test the validity of applying a satellite data set for deriving hectarage estimates over large areas using the crop identification data obtained from the classification of Landsat-TM data,

- To evaluate and compare the accuracy of Landsat-TM data for making improved hectarage estimates *vis a vis* field data collection techniques,

- To assess the accuracy of a hybrid method of area estimation combining satellite and field data, and

- To assess the efficiency of making hectarage estimates using the double sampling over the field survey using stratified random sampling.

The results of the research concerned with these aims will be discussed under the following headings :-

- crop identification,
- hectarage estimation,
- land-cover classification,
- timeliness, and
- cost-effectiveness.

To achieve the research aims, the study used the following data sets :-

- Aerial photography covering most of the study area acquired by BKS Surveys in the summer of 1971 at 1:10,000 scale.

- 1 : 50,000 Ordnance Survey maps for the area dated 1976.

- Field data obtained by applying stratified random sampling. Forty four $1km^2$ sample units were visited in summer 1988 and the field data were collected using a pre-prepared questionnaire.

- Satellite data obtained by Thematic Mapper sensor onboard Landsat-5. The image was acquired on May 31, 1985 at approximately 9.50 am.

7.1 CROP IDENTIFICATION

The overall Landsat-TM classification performance obtained for the study area was better than 80 %. Oilseed rape was the easiest crop to discriminate because of the characteristic yellow colour of its canopy in May. This gave the highest classification accuracy (100%) among the agricultural crops used in this study. Crops such as potatoes and spring barley were difficult to separate because of the stage of their growth in May. The Landsat-TM image used for this study was not appropriate for identifying potatoes because the crop had just been planted at the end of May. In the north-east of England, spring barley is usually planted in April and normally its flat-leaf opens at the beginning of July. Therefore, it was not possible to identify the crop using the May scene. Hectarage estimates for potatoes and spring barley could not be produced using May TM scene of County Durham.

The low level of accuracy obtained for the discrimination between winter wheat and winter barley resulted from a lack of spectral separability. The principal reason for this confusion is that both crops have the same cropping cycle and are spectrally similar (particularly in the visible bands). Also a confusion between winter cereals and managed pastures existed because both crops were green at that time of the year (see figure 7.1).

7.2. HECTARAGE ESTIMATION

The following crop type hectarage estimates were obtained for County Durham :-

i) field estimates using stratified random sampling,

ii) crop hectarage estimates produced by multispectral classification of Landsat-TM, and

iii) double sampling area estimates using a regression estimation for both field and Landsat-TM area measurements obtained for each sample units selected by applying a stratified random sampling strategy.

The stratified random sampling approach implemented for this study was designed to produce a data base which could be analysed statistically in several ways. The information obtained from the field survey was manipulated in order to produce both field and regression estimates for agricultural crops.

Using a double sampling method based on the combination of both Landsat-TM and field data, regression hectarage estimate was produced for each crop type in County Durham. The results showed that the regression estimator was always more efficient than the field estimator. Clearly, the regression estimator has reduced the imprecision in all strata and was more efficient in some strata than others. The maximum increase (113 %) in relative efficiency produced by the use of regression estimation in this study was obtained for oilseed rape in stratum 3. As illustrated in table 6.15, the relative efficiency (RE) gave values of more than 1.0 in all strata. This indicates that a gain in precision was achieved by using Landsat-TM in conjunction with the field data.

The sampling error estimated for a 95% confidence level associated with field estimates were reduced by applying regression estimation (table 7.1). However, these figures suggest to conclude that regression estimates always reduce the sampling error associated with it, which in turn makes the area estimates more precise.

Table 7.1

Estimate of the standard error associated with the hectarage estimates produced for the study area

Crop	Field hectarage Estimates			Regression Area Estimates			Landsat only
	Estimate	SE	SE 95%	Estimate	SE	SE 95%	Estimates
OSR	5306.9	1346.59	2693.18	4801.3	257.7	515.39	4392.1
WW	12253.5	1784.29	3568.57	13579.8	921.86	1843.72	11633.4
WB	13324.61	2243.92	4487.83	9638.5	1451.64	2903.28	15933.2
Past.	71437.0	4407.01	8814.02	88202.7	3144.55	6289.1	84250.1

As shown in the table the regression estimator was always more efficient than the field estimator. In other words, the hybrid technique, combining both satellite and field area measurements, has produced more efficient crop area estimates than the estimates obtained by using field data alone for the stratified random sample used.

The low RE figures produced for some strata result from one or more of the following reasons (see figure 7.1):-

i) In some strata there were too few data points to have confidence in regression parameters. For instance, in stratum 4, winter barley existed in only one sample unit.

ii) The quality of historical data had a great influence on the regression analysis. In some instances, there was disagreement between the Landsat and field area measurements because of error in the 1985 land-cover information given by some farmers, especially those who do not keep records on their farms. Also, the confusion between different agricultural crops has caused a divergence between the two area measurements.

7.3. LAND-COVER CLASSIFICATION

A large area was mapped by multispectral classification of land-cover types using Landsat-TM digital data. The study produced a classification map of thirteen land-cover types with more than 80% accuracy. Not all land-cover categories in level V of land-cover classification system designed for the study area were included in the multispectral classification map produced. The main reason was that some land-cover types could not be identified on the Landsat image used in this study (see figure 7.1). Nevertheless, the results of a discriminant analysis of the differentiation among the land-cover types in County Durham using Landsat-TM was very encouraging because the high accuracy obtained.

7.4. TIMELINESS

The results obtained from this study indicate that the timing of Landsat

Fig. 7.1
Schematic Diagram illustrating the Interrelated Factors Affecting Crop Identification and Area Estimation in County Durham

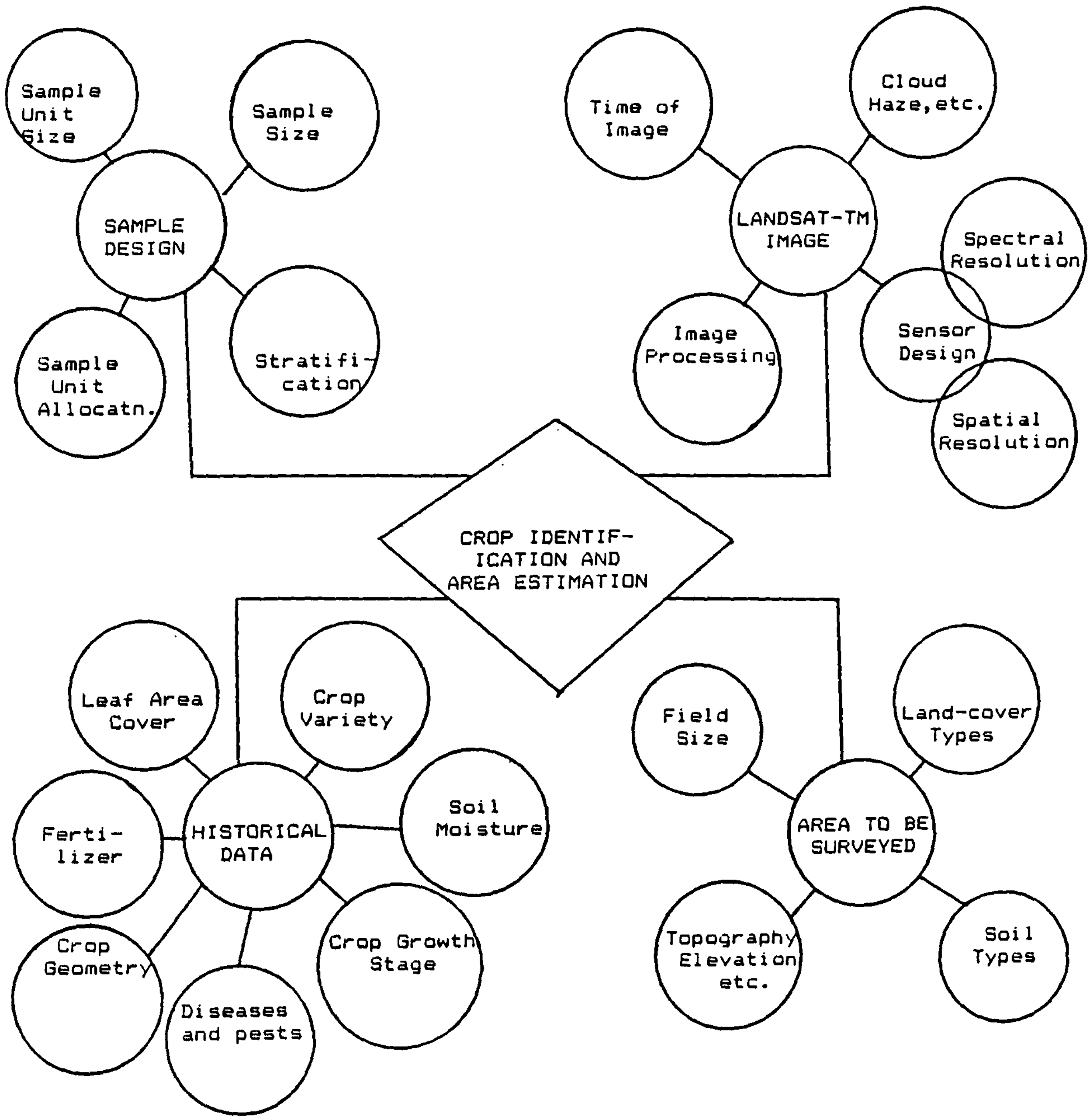


image acquisition was a major factor influencing the accuracy of crop identification. The land-cover classification map produced did not include all the categories illustrated in the system designed for the study area. This is because the image acquired in May was not appropriate for some land-cover classes to be discriminated.

The atmosphere can greatly affect the availability of satellite remote sensing for agriculture. One of the main atmospheric examples is the cloud cover which may prevent a full Landsat cover for the whole area. Cloud cover is a critical factor as far as the application of Landsat data in agriculture in County Durham is concerned. Appendix A presents the weather data obtained by the University meteorological station in Durham. It illustrates the occurrence of dry and cloud-free days through the growing season (see table 2.1). The data presented in the Appendix shows that through the growing season there are very few cloud-free days which makes the acquisition of a cloud-free image for the area difficult.

As described in chapter two, one characteristic of the study area is the spread of hill fog in the west and the "Sea-fret" from the east. These factors can affect the quality of the satellite data obtained from ground reference measurements. In this study haze affected a part of the study area which in turn influenced the Landsat-TM multispectral classification process. To overcome the problem a separate classification was carried out on the area affected by haze by choosing separate training data sets for those areas. This method is a time consuming procedure especially when the main objective is to benefit from the rapidity of remote sensing. Stratification on the environmental basis was seen to be efficient process in these circumstances.

The aerial photographs (AP) used in this study were a useful guide in the sampling design of the field survey, especially when the sample units were transferred from 1:50,000 OS maps to the ground. They were also used in mapping the boundaries of each sample unit and to measure the area of each cover type in SUs. Some problems arose in the use of APs due to the changes which have taken place on the ground in the period between 1971, when these APs were taken, and 1985, when the Landsat-TM image was acquired. The 1:25,000 Ordnance Survey maps were used for surveying those sample units with no air photography coverage. The results reveal that these OS maps can be successfully used instead of APs. The main reason was that the field boundaries are very clear on these maps. Also, this will in turn reduce the cost of acquiring a full coverage of AP for the whole County.

7.5. COST-EFFECTIVENESS

An analysis of whether the increased efficiency gained by applying the regression estimator is cost-effective is difficult due to the lack of precise cost figures for the comparison. For instance, no information is available on the cost of the agricultural survey carried by MAFF in their June postal questionnaire. Therefore, it is not possible to make a final cost comparison between the methods applied in this research and that used by MAFF. Previous studies have reported that the satellite-based techniques for agricultural crop area estimation are cost-effective when implemented over large geographic areas (LACIE 1979 ; Latham *et al* 1982 ; Hanuschak *et al* 1982 ; Hafner *et al* 1982 ; Angelis and Gizzi 1984).

7.6. IMPLICATIONS OF RESEARCH FOR COUNTY DURHAM

This research study demonstrates the ability of Landsat-TM data to discriminate between agricultural crops in the study area. The results obtained emphasized that the satellite data can be used for identification of agricultural crops over large geographic areas with small field sizes and different environmental and physical features.

The most recent land-use maps available for the area go back to early 1960s. Satellite data can be a very good source for producing more recent detailed land-use maps by multispectral classification of Landsat-TM data. The details of the map produced in this study can be extended to include specific land-use types where spectral discrimination is possible.

The quality of field data was affected by errors included in 1985 land-cover information given by some farmers, especially those who did not keep records on their farms. To minimise the effect of such errors, the study indicates the need for selected calibration units (CUs) which will be useful for accurate calibration of remotely sensed data. These calibration areas need to be selected on a stratum by stratum basis in order to fully sample the range of land-use or crop types present in each area. This will allow the distribution of test points within each stratum to reflect a greater range of crops covering all those which occur within a stratum.

These calibration units could take into account a range of field shapes in order to minimise the errors resulted from misclassification of digital data due to the possible association of crops with a particular shape of fields.

The information obtained from those defined CUs will improve the classification accuracy of any remote sensing surveys which will be carried on in the future. Lack of such information leads to low RE estimates for both field and remote sensing surveys.

Using a stratified approach allows each stratum to be analysed separately thereby lessening the reliance on cloud free imagery for the whole county on any given date. Therefore, hectarage estimates could be obtained using both field and Landsat data for those strata which are cloud free. On the other hand strata which are cloud covered would have to rely on previous imagery or simply use only field estimation technique, while using only field estimate for those strata with cloud cover imagery. Also, different crops might be better identified at different times of the year in some strata because of agronomic practice in that particular stratum.

The study reveals the possibility of linking remote sensing data with existing county based information systems. For instance, the ability to overlay Landsat-TM image to the administrative boundaries and produce statistics at a district, parish or other user defined scale.

Once Landsat data are acquired and processed, they can be used for several other applications such as:

- studying the rural and urban land-use expansion,
- forest inventories and ecological monitoring,

- studying the expansion of open cast mining and its effect on the soil capabilities and on agricultural land, and

- comparison of land-use changes with archived maps.

7.7. RECOMMENDATIONS FOR FUTURE RESEARCH

Based on the results of this work, several areas for further study can be recommended.

The accuracy of classification of certain land-cover types can be greatly improved by either :-

i) selecting imagery from certain times of the year, or

ii) using multidate imagery.

This research shows that the best example for (**i**) is the 100% classification accuracy obtained for oilseed rape using May Landsat-TM imagery for County Durham. If the discrimination accuracy between cereals and managed pastures is to be improved another Landsat image should be acquired in August. Because in May both crops are green colour but in August cereals will be yellow. This time of the year will also be suitable for the identification and hectarage estimation of potatoes. However, increased cost and unavailability of Landsat-TM cloud-free scenes for the area may strongly mitigate against having multidate Landsat data. Taking these factors into account, further research could be directed towards using the multipolarized radar data into a crop identification scheme to suit the the environmental conditions of north-east England.

An important factor to be considered when obtaining satellite seasonal coverage is the percent of cloud-free days. Cloud cover may place a great restriction on the scheduling of the satellite image acquisition over County Durham because of the relatively low number of cloud-free days throughout the year, particularly during the growing season. Therefore, the agricultural application of remote sensing in the county should investigate the supplementary use of microwave data (i.e. AIRSAR or ERS-1 data). One of the most important characteristics of radar is that it uses its own energy to map surface features. Consequently, it is not restricted by the availability of solar radiation and can therefore operate under any weather conditions such as cloud, haze and fog.

To improve the efficiency of the regression estimates of crop hectarage in County Durham, both the area of the sampling units and the sample size must be increased for specific crops in particular strata because of the uneven distribution of land-cover types in each sample unit and in each stratum.

To improve the precision of the field and regression area estimates the field survey must be take place at the time of the image acquisition. This will minimise errors in the land-cover information given by the farmers because the information can be checked on the ground and will in turn improve the quality of the training data and the classification accuracy.

The aerial photography acquisition time should ideally coincide with the acquisition time of Landsat data in order to avoid the changes in the field boundaries and in land-cover types. The experience gained from this study reveals that 1:25,000 Ordnance Survey maps provide a useful alternative to APs for the implementation of the double sampling technique for this study. Because of its low cost, it is recommended that future projects use 1:25,000 OS maps where appropriate.

To assess the cost-effectiveness of remote sensing methods used in this study to estimate the crop type hectarage, the cost of an existing agricultural statistical survey must be studied. Such studies must be investigated by MAFF in order to make a final cost comparison among all methods.

The results obtained from this study demonstrate the capability and efficiency of transferring the remote sensing techniques to a processing system, perhaps incorporating multisensor data acquisition, capable of producing accurate and precise crop hectarage estimates for Counties throughout the U.K. as an operational service.

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APPENDICES

APPENDIX A

The Daily Meteorological Observations 1984 - 1988

APPENDIX B

I. The Growth Stages of Cereals

II. The Growth Stages of Oilseed Rape

APPENDIX A

Daily Meteorological Observations 1984 - 1986

SOURCE

Durham University Observatory

Department of Geography

University of Durham

STATION DETAILS

The Observatory is situated on a slight hill, 0.86km south-west of Durham Cathedral, and south of the River Wear. The site is open and well-exposed. The location of the site is given by the following co-ordinates:-

National Grid Reference NZ 2672 4156

Latitude and Longitude $54^{\circ}46'06''$ N $01^{\circ}35'05''$W

The instruments recording temperature and rainfall are located on the lawn in front of the south elevation of the Observatory, at a height of +102 metres O.D. The Campbell-Stokes sunshine recorder is located on a parapet at first floor level, and the anemograph and anemometer are housed on the roof of the Observatory.

EXPLANATION OF TABLES

Hour of observation 0900 G.M.T. unless otherwise stated

Monthly averages of rainfall and sunshine refer to the period 1906-1935
Average wind speeds are for 1937-1947. Monthly averages of temperature are for the period 1936-1965.

Columns 2-8 Temperatures. Thermometers are exposed in a standard Stevenson Screen. Maximum readings are thrown back. Earth thermometers (30 cm and 100 cm under grass) are Symons pattern glass thermometers in steel tubes. All thermometers are graduated on the Centigrade scale (°C)

Column 9 Rainfall. All readings are thrown back and refer to measurements made in a standard 5 inch diameter rain guage. Tr = Trace (less than 0.05 mm)

Column 10 Snow. Depth of snow in cm

Column 11 Sunshine. The recorder is of the Campbell-Stokes pattern sited 6 metres above ground level (+ 108 metres O.D.)

Column 12 State of ground - Code figures:

In 1982 the method of recording was changed. In this part of the record a figure in the first column refers to ground conditions without snow or ice cover; a figure in the second column refers to ground conditions with snow or ice cover.

Without snow or ice cover

0	Surface dry
1	Moist
2	Wet
3	Ground flooded
4	Frozen
5	Glaze on ground

With snow or ice cover

0	Ground covered by ice
1	Compacted wet snow with or without ice
2	Compact or wet snow on over half the ground
3	Even layer of compact or wet snow
4	Snow completely covering the ground
5	Loose dry snow covering less than half of the ground

Column 13 Cloud amount is estimated in oktas (eighths of sky): 0 = sky completely cloudless, 8 = sky completely overcast.

Column 15 Visibility - Code figures:

X	0-19 metres	Dense fog	Screen visible from Observatory
E	20-39 metres	Dense fog	Observatory Cottage visible from Observatory
0	40-99 metres	Thick fog	Trees in drive visible from Observatory
1	100-199 metres	Thick fog	Gate to Observatory on Potters Bank visible
2	300-399 metres	Fog	St Aidan's College visible from Observatory
3	400-999 metres	Moderate fog	Grey College visible from Observatory
4	1000-1999 metres	Very poor visibility	Whinney Hill School visible (NZ 281419)
5	2000-3999 metres	Poor visibility	Gilesgate Moor Estate visible
6	4-9 km	Moderate visibility	Littletown spoil heap visible (NZ 340430)
7	10-19 km	Good visibility	Burnhope Mast visible from Observatory

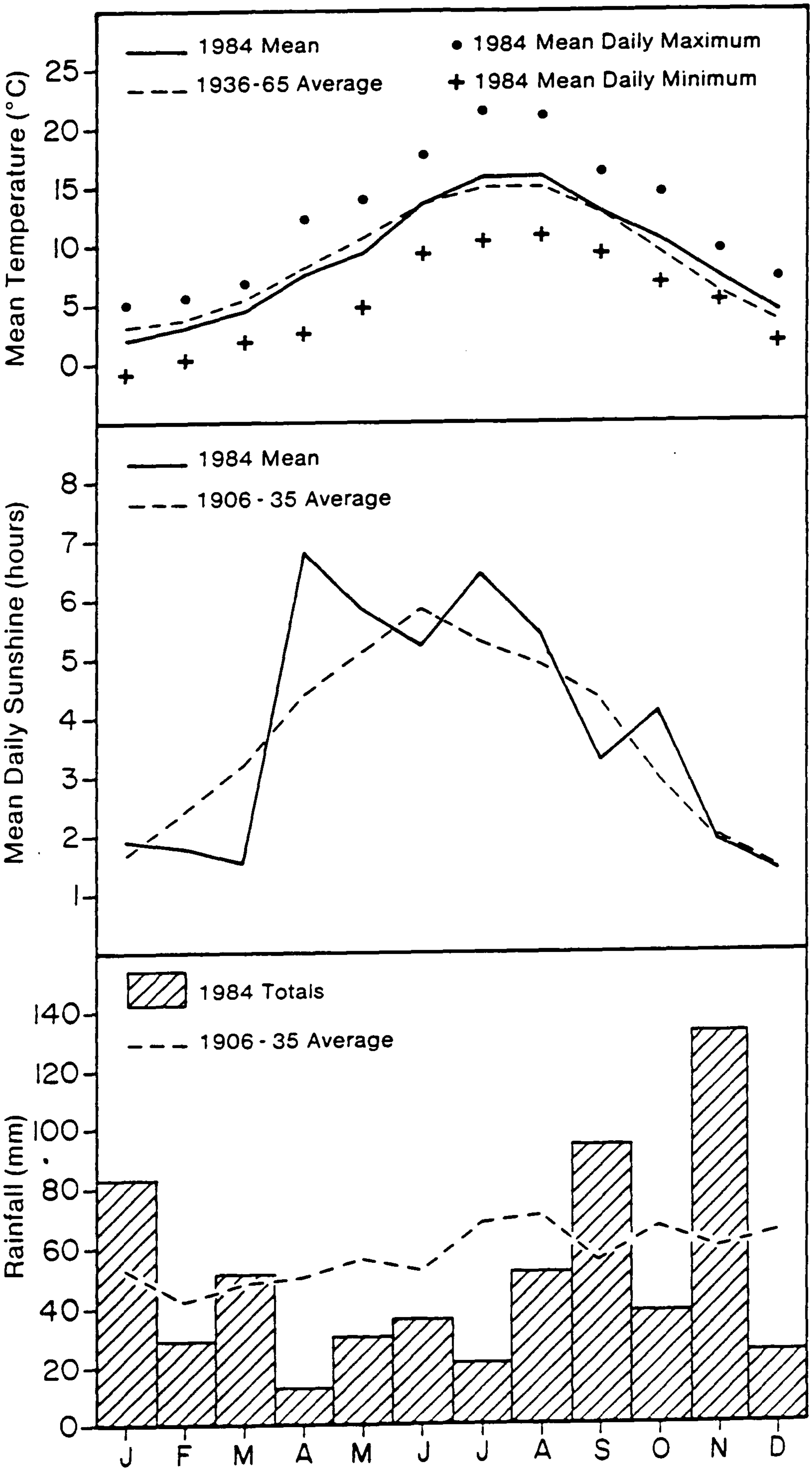
Columns 16-17 Wind speed and direction are measured by a Dines Pressure Tube Anemograph (height of vane 16 metres above ground level: +118 metres O.D. effective height 10 metres)

Daily

Meteorological Observations

1984

MEAN TEMPERATURES, SUNSHINE AND RAINFALL AT DURHAM 1984



DAILY OBSERVATIONS AND WEATHER

January 1984

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SNOW cm. Lying 0900 hours	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	6.5	5.2	7.4	5.2	2.2	6.6	7.1	0.1		0.0	1	3	01	7
2	5.1	3.2	10.1	3.9	1.0	5.9	7.0	5.9		0.0	1	3	02	6
3	1.7	0.5	3.5	-2.0	-2.5	5.9	6.9	1.1	2	0.9	5	8	75	4
4	2.0	0.8	6.9	-0.4	-2.7	4.8	7.0	Tr		4.8	1	2	01	6
5	6.6	5.6	7.5	-1.0	-5.0	4.5	7.0			5.0	1	4	02	6
6	5.3	3.4	7.4	4.5	0.5	4.7	6.9	0.2		0.9	1	3	01	7
7	2.8	2.0	4.7	2.0	1.2	4.7	6.9	Tr		4.9	1	2	02	7
8	1.4	0.5	4.0	0.5	-2.6	4.2	6.6	1.5		1.0	1	2	02	7
9	-0.8	-1.0	8.5	-1.5	-4.0	3.8	6.5	0.1		0.0	4	5	03	6
10	8.4	7.3	10.5	-1.1	-2.6	3.5	6.5	1.6		0.0	1	5	02	6
11	7.3	6.5	10.7	7.0	5.2	4.6	6.2	5.5		1.4	1	6	02	6
12	2.5	2.0	11.1	1.3	-0.9	4.6	6.2	3.7		5.2	4	3	01	6
13	5.4	4.0	5.4	-1.0	-2.1	4.5	6.2	8.1		2.1	1	3	02	6
14	1.5	0.2	3.1	-0.4	-2.4	4.2	6.2	Tr	5	3.3	3	2	02	6
15	-0.3	-0.5	2.3	-1.1	-3.1	3.7	6.2	1.1	5	1.1	3	4	03	6
16	2.2	0.6	6.0	-0.9	-2.0	3.5	6.0	7.5	8	0.0	3	8	03	6
17	2.2	1.7	2.9	-1.7	-2.0	3.4	5.9			0.6	1	6	01	6
18	1.7	0.7	3.7	0.6	-2.3	3.4	5.9			6.5	1	2	01	7
19	1.0	0.1	1.2	-0.1	-3.6	3.0	5.8	0.5		4.3	1	4	02	6
20	-1.9	-2.0	1.6	-3.4	-6.8	2.8	5.6			2.6	6	6	03	6
21	-3.6	-3.8	1.2	-5.7	-7.4	2.6	5.6	3.9		2.1	6	3	01	6
22	-0.2	-0.4	0.1	-4.1	-5.1	2.5	5.4	0.7	9	0.0	7	8	72	5
23	0.5	-0.5	0.6	-3.7	-3.2	2.4	5.3	24.5	10	0.0	7	8	73	5
24	-0.1	-0.5	0.5	-0.7	-1.0	2.3	5.0	0.5	16	0.0	8	8	70	6
25	-4.5	-4.5	1.6	-6.6	-9.0	2.3	5.0	1.6	16	1.1	8	2	01	5
26	1.5	1.2	3.6	-7.9	-9.0	2.3	5.0	7.0	14	0.0	4	8	69	5
27	3.6	3.5	4.1	0.8	-1.1	2.3	4.9	2.5	12	0.0	4	8	45	0
28	2.0	1.9	3.1	1.5	-0.2	2.2	4.8	2.6	8	0.0	4	8	45	0
29	2.3	2.1	6.1	0.8	0.4	2.2	4.7	0.1	4	3.5	2	8	45	1
30	1.7	1.1	3.2	-0.5	-3.3	2.2	4.7	3.3	2	0.4	2	3	01	6
31	1.0	0.2	5.0	-0.1	-4.2	2.2	4.7	0.1	1	7.1	1	1	01	6
MONTH	2.1	1.3	4.8	-0.8	-2.5	3.6	5.9	83.7		58.8		4.7		
AVERAGE			5.3	-0.1				49.3		50.2				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
83.7mm	169.8%	58.8 hrs	117.1%	24.2%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	26	08	Cloudy, strong wind continuing, rain at night
2	27	14	Cloud, strong wind continuing
3	26	20	Strong winds, snow showers. Cold day
4	33	09	Frost, cloudy at first, becoming brighter, cold
5	26	16	Frost, cloudy becoming brighter with sunny intervals
6	20	02	Bright at first, becoming cloudy
7	28	16	Bright with sunny intervals, strong winds
8	34	10	Cloudy, ground frost, becoming brighter, with snow showers
9	24	01	Frost, cloudy, rain
10	22	09	Cloudy, frost, rain
11	21	01	Cloudy, mild, rain, becoming brighter with sunny intervals, rain at night and strong wind
12	28	12	Cloudy, ground frost, cold, wind moderating. Strong winds at night
13	31	27	Cloudy becoming brighter, slight frost, strong wind, HG 76 knots, snow showers
14	25	14	Cloudy, frost, snow showers, strong wind
15	25	10	Cloudy, sold, snow showers
16	16	05	Cloudy, heavy snow showers, sleet, rain late afternoon. Strong winds at night. HG 75 knots at about 6.30 p.m.
17	30	15	Cloudy, wind moderating, frost, cold, sunny intervals
18	29	15	Ground frost, bright and sunny periods, cold day
19	35	10	Cloudy, frost, becoming bright with sunny intervals, slight snow
20	C A L M		Cloudy, frost, becoming brighter with sunny intervals. showers
21	22	02	Cloudy, becoming brighter with sunny intervals. Frost, snow showers
22	19	06	Cloudy, frost, snow showers. Snow covering the ground completely
23	12	05	Cloudy, frost, heavy snow showers. Snow covering the ground
24	02	07	Cloudy, slight snow showers, frost
25	22	02	Cloudy, becoming brighter, frost, sunny intervals
26	10	15	Rain at first, becoming sleet and snow showers
27	09	01	Fog, rain
28	C A L M		Fog, rain
~~29~~	~~20~~	~~02~~	~~Fog at first, becoming brighter with sunny intervals~~
30	22	03	Frost, cloudy, becoming brighter with sunny intervals, rain after-
31	32	03	Frost, bright and sunny noon
MEAN		8.4	
AVERAGE		9.6	

DAILY OBSERVATIONS AND WEATHER

February 1984

DATE	TEMPERATURE °C							RAIN-FALL mm.	SNOW cm. Lying 0900 hours	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
	Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass							
1	0.5	0.1	5.2	-4.7	-6.8	2.2	4.6	5.0		0.0	4	8	03	5
2	4.9	3.9	7.0	0.1	-1.0	2.2	4.6	0.2		1.9	2	4	01	6
3	6.2	4.9	6.8	3.2	0.5	2.3	4.6	2.3		6.1	1	6	03	6
4	2.7	2.3	9.5	2.2	-1.2	2.8	4.6	1.7		0.5	1	8	62	5
5	2.4	0.7	6.0	0.7	-1.6	3.2	4.5	2.7		6.0	1	1	01	6
6	5.0	3.5	5.8	1.5	-0.1	3.3	4.6	1.4		1.5	2	7	64	6
7	3.3	1.1	5.2	0.4	-2.0	3.2	4.6	3.4		7.3	4	2	01	6
8	2.8	1.4	6.0	1.6	-1.4	3.2	4.6	0.1		7.8	1	2	02	6
9	3.1	1.5	8.6	1.0	-3.3	3.0	4.6			8.0	4	2	02	6
10	7.0	5.9	10.0	3.1	0.5	3.0	4.6	0.2		2.7	1	1	02	6
11	6.8	6.1	8.4	4.7	0.5	3.9	4.7	Tr		0.2	1	4	03	5
12	5.3	4.4	8.6	4.8	2.8	4.3	4.7			1.4	1	6	02	6
13	-1.2	-1.4	3.0	-1.6	-1.8	4.2	4.7			2.7	1	8	03	4
14	-1.0	-1.3	5.6	-2.7	-5.2	3.7	4.7	Tr		0.3	4	7	02	4
15	1.1	0.7	2.5	-1.2	-1.6	3.7	5.0			0.3	1	8	02	5
16	-1.9	-2.0	1.2	-2.0	-2.2	3.5	4.9			0.0	4	9	45	3
17	1.2	1.1	6.1	-2.0	-2.1	3.5	4.9			1.3	1	9	45	3
18	0.3	0.1	3.8	-0.4	-0.5	3.6	4.9			0.4	1	9	45	1
19	-0.1	-1.1	2.0	-1.1	-3.6	3.3	4.8			1.3	4	7	02	5
20	0.9	0.7	2.3	-1.7	-4.2	2.9	4.8	6.1		0.1	4	8	70	5
21	2.2	1.9	6.0	0.2	-1.8	2.7	4.7	0.2	2	0.3	3	8	03	6
22	4.5	4.1	7.0	2.0	1.1	3.0	4.7	0.3		0.2	1	8	02	6
23	3.0	1.5	4.0	2.4	1.0	3.5	4.7	Tr		0.0	1	8	02	6
24	2.3	1.0	4.4	1.0	-0.1	3.5	4.5	0.6		0.0	1	8	02	6
25	0.2	0.0	3.5	-1.2	-4.2	3.4	4.5	0.3		0.0	1	8	02	4
26	1.3	0.8	3.2	-0.1	-0.4	3.4	4.6	2.5		0.0	1	8	77	5
27	3.2	2.6	4.0	1.0	0.2	3.4	4.6	0.1		0.0	1	8	03	5
28	3.0	2.0	5.1	1.9	1.2	3.5	4.7	0.2		0.0	1	8	02	5
29	5.1	4.5	11.0	-0.5	-4.5	3.5	4.7	0.4		3.6	1	7	01	6
MONTH	2.6	1.8	5.6	0.4	1.3	3.3	4.7	27.7		53.9		6.5		
AVERAGE			6.0	0.1				38.1		64.1				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
27.7mm	72.7%	53.9 hrs	84.1%	19.4%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	19	02	Frost, cloudy, snow showers, becoming heavy rain
2	31	09	Cloudy, ground frost, becoming brighter with sunny intervals
3	28	10	Cloudy, becoming bright and sunny
4	20	16	Cloudy, ground frost, strong wind, rain at night
5	24	14	Bright and sunny, ground frost, rain at night
6	28	16	Cloudy, intermittant heavy rain and strong wind
7	31	22	Bright, ground frost, strong winds, rain at night
8	33	14	Bright and sunny, ground frost
9	32	06	Bright and sunny, ground frost
10	29	04	Bright and sunny, dry day
11	29	03	Bright and sunny, becoming cloudy
12	22	02	Cloudy, sunny intervals
13	22	06	Frost, cloudy becoming brighter with sunny intervals
14	C A L M		Frost, cloudy becoming brighter, cold and damp, fog at night
15	20	02	Cloudy, frost, dull, cold, fog at night
16	22	08	Fog, frost, cold day
17	20	03	Fog, frost, cold becoming brighter
18	21	10	Fog, frost, cold
19	17	10	Frost, cloudy, becoming brighter with sunny intervals
20	15	03	Cloudy, slight snow showers, frost
21	14	02	Cloudy, wet snow covering ground
22	C A L M		Cloudy, slight rain at night
23	08	05	Cloudy, dull day
24	23	03	Cloudy, slight ground frost, dull
25	C A L M		Frost, cloudy, rain at night
26	C A L M		Frost, slight hail at first, cloudy, cold, rain at night
27	05	05	Cloudy, cold
28	33	01	Cloudy, slight rain at night
29	22	01	Cloudy becoming brighter with sunny intervals
MEAN		6.1	
AVERAGE		8.4	

DAILY OBSERVATIONS AND WEATHER

March 1984

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SNOW cm. Lying 0900 hours	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	5.0	4.5	7.5	4.1	0.5	4.2	4.7	2.0		0.7	1	7	60	6
2	2.1	0.5	4.2	0.3	-1.5	4.5	4.7	1.8		1.0	2	7	01	6
3	2.2	0.5	8.9	0.0	-3.4	4.1	4.8	1.8		7.3	1	1	01	7
4	8.9	8.2	11.0	1.9	-0.4	4.4	4.9	0.7		0.0	1	6	03	6
5	8.4	6.9	12.5	6.3	1.3	5.0	5.3	Tr		4.9	1	5	01	6
6	8.8	6.6	12.7	5.6	-0.1	5.8	5.0			2.8	1	5	02	7
7	6.7	5.5	7.6	5.8	1.9	6.1	5.1			0.0	1	8	03	5
8	5.0	3.6	6.5	3.0	1.1	6.0	5.3			0.6	1	5	01	6
9	6.0	4.0	7.4	1.0	-2.1	5.6	5.5	0.1		1.2	1	3	01	5
10	5.8	4.9	7.5	4.2	2.6	5.8	5.5	1.5		0.0	1	8	02	6
11	5.4	4.5	8.1	3.7	1.6	5.8	5.5	1.1		0.2	1	7	01	6
12	5.0	4.6	5.6	3.3	1.6	5.9	5.6	0.2		0.1	2	8	60	6
13	3.6	2.0	4.0	3.5	1.5	5.6	5.7	1.4		0.3	1	8	03	6
14	3.7	2.4	4.9	2.0	1.0	5.3	5.7	0.1		0.0	1	8	02	6
15	3.0	1.5	4.6	2.3	1.5	5.1	5.7	3.3	1	0.4	1	8	02	6
16	1.4	1.1	5.4	0.2	-1.7	4.8	5.8	0.4		2.3	3	5	01	6
17	1.8	1.4	4.0	0.0	-3.3	4.7	5.8	0.5		0.0	1	6	03	5
18	2.9	1.5	5.5	1.0	0.1	4.7	5.8	0.2		1.4	1	7	03	5
19	1.0	0.3	3.5	0.2	-0.2	4.8	5.6	0.2		0.3	1	8	83	5
20	1.9	0.5	3.2	0.5	0.1	4.6	5.5	0.1		0.2	1	8	03	5
21	1.2	1.0	6.0	-0.4	-1.5	4.6	5.5	Tr		0.6	1	8	71	5
22	1.0	0.9	6.3	-2.1	-4.2	4.5	5.5			1.2	1	8	42	2
23	4.5	3.5	7.4	0.6	-1.8	4.7	5.5	6.0		1.0	1	7	01	5
24	3.8	3.4	3.8	3.4	3.0	5.0	5.6	12.0		0.0	1	7	63	5
25	2.9	1.8	7.5	-0.1	-2.4	4.5	5.6	5.5		3.2	1	8	40	4
26	5.2	5.1	7.4	1.7	1.5	5.0	5.7	4.3		0.0	2	8	65	5
27	6.4	5.0	10.1	2.2	-1.0	5.6	5.5	0.2		8.8	2	3	01	6
28	5.5	4.5	10.0	2.0	-1.4	6.1	5.6	3.5		1.6	1	4	02	6
29	4.5	3.9	7.5	1.9	0.4	6.3	5.7	1.9		2.5	2	5	02	6
30	2.5	2.2	6.8	1.5	-1.3	6.2	5.9	3.0		2.2	2	8	60	5
31	3.1	2.3	6.2	-0.5	-2.9	5.8	5.8	0.4		6.5	2	4	01	5
MONTH	4.2	3.2	6.9	1.9	-0.31	5.2	5.5	52.2		51.3		6.4		
AVERAGE			8.6	1.3				44.9		106.4				

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	C A L M		Cloudy, slight rain at first, becoming brighter
2	31	15	Slight snow showers, strong winds, becoming brighter
3	34	14	Bright and sunny, slight ground frost, rain at night
4	32	05	Cloudy, slight ground frost, rain at night
5	31	06	Bright and sunny. Mild
6	31	09	Cloudy, becoming brighter with sunny intervals
7	03	03	Cloudy, dry
8	05	03	Cloudy, becoming brighter
9	C A L M		Bright and sunny at first, becoming cloudy
10	32	05	Cloudy, rain in tho evening
11	C A L M		Cloudy, rain
12	10	04	Rain at first, cloudy, becoming brighter
13	07	08	Bright at first, cloudy, rain
14	08	06	Cloudy, rain at night
15	07	03	Cloudy, becoming brighter late afternoon
16	C A L M		Snow showers, becoming brighter
17	06	02	Cloudy, ground frost, slight rain
18	06	04	Bright at first, becoming cloudy with sunny intervals
19	C A L M		Cloudy, ground frost, slight snow showers, sunny intervals
20	C A L M		Cloudy, becoming brighter
21	C A L M		Cloudy, slight snow showers, becoming brighter
22	C A L M		Fog, frost, becoming brighter with sunny intervals
23	11	03	Cloudy, ground frost
24	13	01	Rain, heavy at times
25	17	04	Cloudy, frost becoming brighter with sunny intervals
26	10	01	Rain, heavy at times
27	21	01	Bright and sunny, slight ground frost
28	C A L M		Cloudy, ground frost, becoming brighter
29	35	03	Rain, becoming brighter with sunny intervals
30	04	03	Cloudy, slight rain becoming brighter
31	07	05	Snow. Sleet and snow showers. Becoming brighter
MEAN		3.5	
AVERAGE		7.3	

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
52.2mm	116.3%	51.3 hrs	48.4%	14.1%

DAILY OBSERVATIONS AND WEATHER

April 1984

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	4.8	1.9	7.0	0.8	-1.4	5.5	6.0	0.6	9.0	1	3	01	6
2	5.1	4.3	8.9	-0.2	-3.2	5.5	5.6		6.8	2	6	03	6
3	4.1	2.6	8.5	-3.2	-5.9	5.6	6.0		9.5	1	3	01	6
4	4.0	1.7	7.5	-1.8	-4.9	5.8	6.0		9.8	0	3	02	6
5	5.0	3.0	10.0	-3.2	-6.0	5.7	6.0	0.2	9.7	0	2	02	6
6	5.3	4.6	6.2	1.6	-1.2	6.5	6.0	5.3	0.0	1	8	03	6
7	6.2	4.9	8.6	2.7	-0.8	6.3	6.2	0.2	2.0	2	4	01	6
8	5.9	4.9	10.0	0.2	-3.4	6.5	6.2	0.1	0.7	1	6	02	5
9	8.0	5.1	9.4	0.5	-1.7	6.5	6.2	1.5	0.4	1	7	02	6
10	6.1	5.3	9.0	-0.4	-2.7	6.3	6.3	2.4	0.6	1	7	02	5
11	8.8	5.9	10.5	5.2	3.8	6.7	6.4	0.5	7.8	1	3	01	6
12	7.9	4.5	10.9	-0.5	-4.7	6.5	6.4		8.8	1	1	01	7
13	8.7	7.2	12.2	6.0	4.5	6.8	6.5		2.8	1	6	03	7
14	9.3	6.9	11.8	6.8	5.2	7.2	6.5	0.2	2.3	0	6	02	6
15	5.5	3.2	12.4	3.5	2.4	7.5	6.6	1.1	5.6	1	6	02	6
16	7.5	4.5	11.6	2.1	-1.5	7.5	6.6	0.6	8.9	1	2	02	7
17	8.4	5.0	11.5	0.3	-3.6	7.5	6.6	0.2	9.0	1	2	02	7
18	7.6	6.2	11.7	5.3	4.1	7.5	6.9		1.2	1	7	03	6
19	11.7	8.8	12.5	7.3	5.8	7.5	7.0		3.5	0	5	02	7
20	12.5	10.5	16.3	9.5	8.1	7.5	7.0		5.0	0	6	01	6
21	12.7	8.6	18.3	8.2	4.1	7.7	7.1		6.7	0	6	01	6
22	9.8	8.0	12.6	5.0	0.9	7.9	7.3		8.3	0	4	02	7
23	9.1	5.8	15.4	-0.6	-4.2	8.5	7.5		12.5	0	1	02	7
24	11.0	6.5	18.0	1.9	-1.5	9.1	7.6		12.6	0	0	02	7
25	14.5	10.2	19.6	3.0	-0.9	9.8	7.8		12.2	0	1	02	7
26	13.7	11.0	15.0	1.7	-2.3	10.1	8.0		10.8	0	0	02	7
27	7.2	6.9	18.9	4.5	4.0	11.0	8.1		9.1	0	2	02	6
28	13.1	7.0	16.9	4.4	1.1	11.4	8.3		12.2	0	1	02	7
29	7.9	6.5	15.1	2.1	-1.5	11.1	8.3		8.3	0	6	03	5
30	9.0	7.0	16.6	1.0	-3.5	10.6	8.7		11.3	0	2	01	5
MONTH	8.4	6.0	12.4	2.5	-0.4	7.7	6.9	12.9	207.4		3.9		
AVERAGE			11.8	3.3				45.9	134.1				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
12.9mm	28.1%	207.4 hrs	154.7%	49.4%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	08	10	Bright and sunny, ground frost
2	02	04	Bright at first, becoming cloudy, ground frost, sunny intervals
3	24	02	Frost, bright and sunny, warm dry day
4	22	02	Frost, bright and sunny, dry day
5	C A L	M	Frost, bright and sunny, warm dry day
6	04	06	Slight ground frost. Cloudy, rain
7	02	02	Slight ground frost. Bright and sunny
8	34	02	Cloudy, ground frost
9	32	03	Bright at first, becoming cloudy, ground frost. Rain
10	C A L	M	Cloudy, frost, becoming brighter, rain at night
11	29	06	Bright and sunny, showers
12	29	06	Frost, bright and sunny
13	26	07	Cloudy, cool SW wind
14	24	16	Bright at first, becoming cloudy with sunny intervals
15	30	06	Cloudy at first, becoming brighter. Rain and sleet showers
16	30	12	Ground frost. Bright and sunny, sleet showers
17	31	05	Ground frost. Bright and sunny, rain at night
18	20	08	Cloudy, cold SW wind, becoming a little brighter
19	23	14	Quite cloudy, with strong SW wind, mild
20	23	10	Cloudy, becoming clearer with sunny periods
21	16	03	Cloudy, becoming clearer, with long sunny periods. Warm, dry day
22	05	03	Dry, sunny day
23	17	06	Frost. Bright and sunny, dry day
24	18	05	Ground frost. Bright and sunny, warm dry day
25	20	01	Ground frost, bright and sunny, continuing warm and dry
26	05	03	Ground frost, bright and sunny, fog at night
27	18	01	Fog at first, becoming brighter, warm and dry day
28	18	02	Bright and sunny, continuing all day, quite warm. Light SW wind
29	17	05	Cloudy, becoming brighter, ground frost
30	18	02	Ground frost, bright and sunny
MEAN		5.1	
AVERAGE		8.1	

DAILY OBSERVATIONS AND WEATHER

May 1984

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	12.0	9.9	15.6	4.0	-0.5	10.6	8.9		10.4	0	2	02	6
2	13.5	10.0	16.1	5.1	2.1	11.1	9.0		11.2	0	1	02	6
3	6.7	6.0	15.5	3.5	3.9	11.2	9.0		6.5	0	8	03	5
4	6.8	6.4	14.8	4.6	2.6	11.5	9.1		5.8	0	8	02	4
5	9.2	8.8	14.8	1.2	0.2	11.2	9.2		7.7	0	2	01	5
6	9.4	6.6	9.9	6.6	4.2	12.1	9.5	Tr	1.2	0	5	03	6
7	6.9	5.0	8.9	4.7	0.0	11.1	9.6	Tr	1.6	0	6	02	6
8	5.5	3.8	10.5	2.9	0.4	10.8	9.6		7.6	0	7	03	6
9	9.0	6.3	11.1	2.0	1.1	10.6	9.6	0.4	1.2	0	7	02	6
10	9.5	7.5	11.2	0.6	-3.0	10.1	9.5	4.3	1.0	1	8	62	6
11	11.0	8.1	12.4	3.0	1.5	10.0	9.6		12.3	1	3	01	7
12	10.4	7.3	12.4	-0.6	-4.6	10.1	9.5		11.8	1	4	02	6
13	11.2	6.2	13.6	-2.2	-6.3	10.1	9.6		12.1	0	1	01	7
14	12.0	7.1	16.0	-0.5	-3.5	10.2	9.6		13.4	0	1	02	7
15	13.5	9.1	15.9	3.3	1.3	10.9	9.7		11.5	0	2	02	7
16	11.1	8.0	13.8	5.4	1.9	11.2	9.7		0.0	0	7	03	6
17	10.6	9.5	13.5	5.8	2.8	11.2	9.7	0.3	3.7	0	7	02	6
18	8.0	6.4	11.5	6.6	5.6	11.2	9.7	0.2	0.0	0	8	03	6
19	11.4	10.1	16.6	5.0	2.5	11.2	10.0	6.2	7.1	0	3	01	6
20	11.6	10.3	12.9	6.9	5.0	11.6	10.0	4.1	0.7	1	6	02	5
21	7.5	7.0	12.1	5.5	4.6	11.3	10.1	7.3	0.2	1	8	03	5
22	11.1	10.0	14.1	7.2	6.6	11.1	10.1	0.8	0.2	1	8	02	5
23	13.9	11.5	19.2	7.8	6.0	11.5	10.2		10.7	0	4	01	6
24	18.8	15.0	20.4	8.3	4.5	12.6	10.2	1.0	10.9	0	2	02	7
25	8.1	7.3	10.3	7.4	7.0	13.0	10.3	Tr	0.0	1	8	03	6
26	9.5	6.9	12.1	6.2	4.9	12.6	10.6	2.1	3.1	0	4	02	7
27	6.4	5.9	8.8	3.7	0.7	11.8	10.6	2.4	0.0	1	7	62	5
28	8.5	7.8	11.1	5.7	5.4	11.3	10.6	Tr	0.0	1	6	02	6
29	10.0	8.0	17.1	5.6	3.8	11.1	10.5		8.4	1	6	01	7
30	17.1	13.2	19.8	3.3	2.0	12.2	10.5		12.6	0	2	01	7
31	15.6	11.7	19.5	7.7	5.3	13.1	10.6	1.6	12.0	0	1	01	7
MONTH	10.5	8.3	13.9	4.7	2.2	11.3	9.8	30.7	184.9		5.1		
AVERAGE			14.8	5.5				54.1	159.96				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
30.7mm	56.8%	184.9 hrs	115.6%	37.3%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	04	04	Slight ground frost, bright and sunny
2	04	04	Bright and sunny
3	21	03	Fog at first, cloudy, becoming brighter with sunny periods
4	20	04	Fog at first, cloudy becoming brighter with sunny intervals
5	CALM		Bright and sunny
6	05	07	Bright and sunny at first, becoming cloudy
7	03	08	Cloudy with sunny intervals
8	02	04	Bright at first, becoming cloudy with sunny intervals
9	29	04	Cloudy, becoming brighter late afternoon
10	35	05	Cloudy, rain, cold day
11	09	04	Bright and sunny, warm,dry
12	07	02	Bright and sunny, frost
13	09	02	Frost, bright and sunny
14	21	03	Frost, bright and sunny. Warm and dry
15	20	02	Bright and sunny. Warm and dry
16	CALM		Cloudy all day
17	10	03	Cloudy becoming brighter. Rain at night
18	03	05	Cloudy, slight rain
19	12	01	Bright and sunny. Rain at night
20	05	02	Bright at first, becoming cloudy. Rain at night
21	34	06	Rain at first, cloudy, rain at night
22	05	10	Rain at first, cloudy, sunny intervals
23	03	03	Bright and sunny. Warm and dry
24	01	06	Bright and sunny. Warm, dry day
25	05	05	Rain at first, cloudy
26	02	12	Cloudy with sunny periods
27	35	14	Cloudy, rain
28	03	10	Cloudy,rain
29	03	05	Cloudy, becoming brighter with sunny intervals
30	09	01	Bright and sunny. Warm & dry. (Annular eclipse 6.14-8.00 pm)
31	21	03	Bright and sunny. Warm, dry day
MEAN		4.6	
AVERAGE		7.0	

DAILY OBSERVATIONS AND WEATHER

June 1984

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	13.2	11.4	14.9	10.0	9.0	13.3	10.8	5.6	0.6	0	7	03	6
2	12.2	9.6	15.2	6.9	4.6	13.3	10.0	3.2	8.3	1	5	01	6
3	10.0	9.7	15.3	7.1	3.9	13.1	11.1	1.8	0.6	1	8	03	5
4	12.4	11.3	14.5	5.4	2.5	12.5	11.1	10.5	0.1	1	8	62	5
5	11.0	10.8	12.1	10.0	8.2	13.0	11.2	6.7	0.1	2	9	43	2
6	12.0	11.7	15.2	9.4	8.9	12.8	11.2	0.1	0.0	2	8	03	4
7	15.2	13.5	17.5	9.5	7.5	12.8	11.2		6.8	1	5	01	6
8	10.3	9.2	14.2	6.6	3.2	13.6	11.4		4.3	0	7	02	6
9	12.4	10.4	16.2	6.0	4.3	13.4	11.4		9.0	0	5	01	6
10	11.8	10.8	14.3	5.2	2.6	13.8	11.4		0.2	0	7	03	5
11	13.9	11.8	17.5	8.5	6.5	13.8	11.6		5.0	0	5	01	6
12	15.9	12.2	16.8	10.8	7.5	14.2	11.6		2.2	0	5	01	7
13	15.5	14.1	17.2	12.4	10.5	13.8	11.6	0.9	0.0	0	8	03	6
14	14.7	11.0	18.3	8.5	5.8	13.5	11.8		7.2	0	6	01	6
15	15.0	12.6	21.2	7.8	2.3	13.7	12.0		7.0	0	6	02	6
16	19.5	17.0	23.0	13.5	9.6	14.5	12.0	0.1	4.3	0	5	02	6
17	21.5	18.1	22.3	13.9	10.7	15.1	12.0	4.8	5.3	0	5	02	6
18	18.1	15.4	23.2	10.5	6.8	15.5	12.4	Tr	5.8	0	7	03	6
19	20.1	17.9	25.0	13.8	10.2	16.1	12.4		8.3	0	5	01	6
20	20.6	16.9	23.2	11.2	7.5	16.4	12.6	0.1	9.0	0	3	01	6
21	14.5	10.5	16.3	8.4	3.9	16.2	12.7	0.5	9.4	0	4	02	6
22	16.1	11.9	16.6	9.9	8.5	15.5	13.0		7.0	0	4	02	6
23	13.5	9.7	14.5	7.9	4.7	14.7	13.0		4.5	0	8	03	7
24	14.1	10.9	17.8	5.9	3.0	14.1	13.0		2.7	0	6	02	7
25	17.6	13.0	20.2	12.0	10.2	14.5	13.0		12.7	0	4	02	7
26	17.0	13.4	22.0	12.1	9.5	14.8	13.0		10.5	0	7	03	6
27	16.9	13.6	19.5	13.5	11.5	15.5	13.0	2.5	6.4	0	4	01	7
28	12.5	8.8	16.1	7.9	5.5	15.2	13.0		7.8	1	6	03	7
29	13.3	9.0	15.6	6.1	2.2	14.8	13.0		6.8	0	6	02	7
30	14.4	9.7	16.1	6.0	3.0	14.6	13.2		7.6	0	4	01	7
MONTH	14.84	12.2	17.7	9.22		14.3	12.0	36.8	159.5		5.9		
AVERAGE			17.9	8.5				50.0	174.6				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
36.8mm	73.6%	159.5hrs	91.4%	31%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	21	04	Cloudy with sunny intervals, rain at night
2	24	06	Bright and sunny, warm dry day, rain at night
3	09	09	Thunderstorm, rain, cloudy, mild. Clearing by late afternoon
4	04	03	Cloudy. Thunder showers at night
5	09	08	Fog, damp day, rain at night
6	C A L M		Cloudy, dull, damp day
7	02	08	Cloudy at first becoming brighter with sunny intervals
8	01	08	Cloudy becoming brighter with sunny intervals
9	06	02	Bright and sunny, warm dry day
10	05	02	Cloudy dull day
11	23	02	Bright and sunny, cloudy with sunny intervals
12	24	13	Bright and sunny. Strong SW wind. Cloudy with sunny intervals
13	25	08	Cloudy, rain
14	32	07	Bright and sunny at first, becoming cloudy with sunny intervals
15	C A L M		Bright and sunny, warm dry day
16	C A L M		Bright and sunny at first, becoming cloudy
17	23	04	Bright and sunny, becoming cloudy, with thunderstorm
18	21	04	Bright at first, becoming cloudy, warm, dry day
19	24	04	Bright and sunny, warm, dry day
20	20	04	Bright and sunny, warm dry day, rain at night
21	31	11	Bright and sunny, cool NW wind, rain at night
22	29	17	Bright and sunny, strong westerly wind. Becoming cloudy
23	24	10	Dull with westerly winds and sunny intervals
24	34	10	Cloudy with sunny intervals
25	31	17	Bright and sunny, strong N to NW winds
26	32	11	Cloudy with west wind continuing and sunny intervals
27	30	14	Bright and sunny, rain at night
28	02	09	Bright and sunny, becoming cloudy with sunny intervals, NW winds con
29	33	10	Bright and sunny, NW wind continuing
30	01	05	Bright at first, becoming cloudy, with sunny intervals, dry day
MEAN		7	
AVERAGE		6.3	

DAILY OBSERVATIONS AND WEATHER

July 1984

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	15.6	12.0	20.1	8.2	4.5	14.8	13.2	5.2	7.3	0	4	02	7
2	11.1	9.2	14.3	8.3	7.1	15.0	13.2	Tr	1.6	1	6	03	7
3	14.1	11.5	17.6	5.6	2.5	14.4	13.3		11.1	0	4	01	7
4	15.0	12.0	21.0	4.5	1.8	14.9	13.2		11.0	0	1	01	6
5	13.1	11.6	21.6	6.4	3.5	15.2	13.3		8.1	0	6	03	6
6	21.0	15.5	26.0	7.7	5.8	15.9	13.3		10.7	0	3	01	7
7	21.0	20.7	26.2	9.0	3.6	16.2	13.5		11.7	0	2	02	7
8	21.0	16.1	26.0	10.1	7.0	16.4	13.5		11.7	0	6	02	6
9	21.3	18.2	22.5	12.5	9.0	17.0	13.7		7.3	0	6	02	5
10	18.2	15.2	22.3	13.9	9.5	16.9	13.7		4.9	0	7	02	6
11	17.6	15.9	22.1	11.2	7.2	16.5	13.9		9.6	0	6	02	6
12	18.1	16.5	21.0	10.8	7.1	16.3	14.0		6.8	0	6	02	6
13	17.6	13.2	20.2	9.7	5.4	15.9	14.0	3.1	5.7	0	5	02	6
14	12.7	12.5	19.6	11.4	9.5	15.7	14.0	0.3	3.2	1	8	02	5
15	15.9	12.2	18.1	10.0	7.2	16.0	14.1	0.4	4.6	0	4	01	7
16	16.9	13.3	18.2	11.7	7.5	16.0	14.0		4.3	0	6	03	7
17	18.7	14.9	24.0	10.5	7.4	16.0	14.0	0.1	5.1	0	6	02	7
18	16.5	15.6	21.5	15.1	13.0	16.6	14.0	0.3	7.0	1	8	62	5
19	15.5	14.0	18.6	12.5	11.4	17.0	14.0		0.5	0	8	03	6
20	18.5	15.7	23.0	9.5	6.0	16.5	14.3		10.1	0	5	01	6
21	13.6	12.5	19.2	12.6	11.1	16.6	14.4		3.3	0	8	01	6
22	14.0	12.3	23.9	12.4	11.1	16.5	14.4		2.9	0	8	01	6
23	16.5	12.8	21.1	6.2	2.5	16.0	14.5		6.9	0	3	01	7
24	17.2	12.7	22.2	8.3	4.8	16.2	14.5		7.7	0	7	03	7
25	19.5	14.9	24.0	8.3	4.0	16.6	14.4	0.3	12.4	0	1	01	7
26	16.5	14.4	21.0	12.9	10.6	17.1	14.5		4.5	0	7	03	6
27	15.5	13.1	19.2	9.5	5.7	16.7	14.5	8.7	0.0	0	7	02	6
28	19.2	16.6	20.3	13.6	11.0	16.4	14.6	Tr	0.0	1	7	02	6
29	19.3	15.4	22.5	15.1	12.5	16.6	14.8		9.8	0	4	01	6
30	19.9	15.7	22.8	9.7	6.7	16.8	14.6	3.0	8.5	0	4	02	6
31	15.2	14.9	20.1	13.6	9.1	16.6	14.5	Tr	4.5	1	8	63	5
MONTH	16.9	14.2	21.3	10.3	7.2	16.2	14.0	21.4	202.8		5.5		
AVERAGE			19.4	10.1				65.8	159.3				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
21.4mm	32.5%	202.8	127.3%	39.3%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	01	02	Bright
2	01	10	Cloudy, cool and sunny intervals
3	34	02	Bright and sunny, warm dry day
4	C A L	M	Bright and sunny, warm dry day
5	08	01	Cloudy becoming bright and sunny, warm dry day
6	22	04	Bright and sunny, warm dry day
7	23	05	Bright and sunny, warm dry day
8	18	03	Bright and sunny, warm dry day
9	C A L	M	Bright and sunny
10	22	02	Cloudy with sunny intervals
11	23	07	Bright and sunny, becoming cloudy with a cool SW breeze
12	22	10	Bright and sunny, dry day
13	32	10	Bright and sunny
14	C A L	M	Rain, becoming brighter with sunny intervals
15	04	06	Cloudy with sunny intervals, rain at night
16	05	04	Cloudy with sunny intervals
17	35	04	Cloudy becoming brighter with sunny intervals
18	C A L	M	Rain at first, clearing to give a bright, sunny, warm day
19	03	07	Cloudy, becoming brighter late afternoon
20	C A L	M	Bright and sunny
21	08	02	Cloudy, becoming brighter with sunny intervals
22	C A L	M	Cloudy, becoming brighter with sunny intervals
23	21	05	Cloudy, becoming brighter with sunny intervals
24	14	02	Bright and sunny at first, becoming cloudy, warm, dry and sunny
25	17	01	Bright and sunny, warm, dry day
26	07	01	Cloudy, becoming brighter with sunny intervals
27	28	08	Cloudy, rain
28	27	09	Cloudy
29	24	12	Bright and sunny
30	23	07	Bright and sunny, warm, dry day
31	C A L	M	Rain, cloudy with sunny intervals
MEAN		4.16	
AVERAGE		6.1	

DAILY OBSERVATIONS AND WEATHER

August 1984

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	16.9	13.5	22.5	9.0	4.5	16.2	14.6	5.6	6.3	0	5	01	7
2	14.5	14.0	15.5	12.5	8.6	16.2	14.6	10.2	0.0	1	8	63	5
3	13.1	13.0	13.7	12.6	11.3	16.2	15.6	22.5	0.0	2	8	63	5
4	12.3	12.0	14.9	11.4	10.0	15.0	14.7	0.5	0.0	2	8	63	5
5	14.5	12.4	18.8	9.8	6.3	15.0	14.5	Tr	2.6	1	8	02	7
6	14.4	12.0	17.2	7.5	4.0	15.1	14.5	1.5	0.2	1	8	02	7
7	12.5	12.0	18.1	10.3	7.5	15.0	14.5	3.5	4.0	1	8	62	6
8	15.0	14.0	18.9	12.5	10.4	15.3	14.4	Tr	1.8	1	8	01	6
9	18.5	15.0	19.0	10.2	7.0	15.7	14.4		2.2	1	5	03	7
10	15.0	12.4	21.4	7.0	2.8	15.5	14.4		10.7	1	2	02	7
11	19.1	15.0	23.4	7.0	4.0	15.9	14.4		11.1	0	2	02	7
12	18.0	14.4	22.2	9.1	5.9	16.5	14.5		11.3	0	2	02	7
13	12.5	11.3	23.7	9.2	4.8	16.8	14.5		6.5	0	8	01	5
14	20.5	16.5	23.6	10.6	7.1	16.8	14.6	0.1	5.4	0	4	02	6
15	19.0	15.3	21.1	12.0	7.5	17.0	14.7		4.5	0	4	02	6
16	16.9	15.1	22.3	10.9	7.2	16.8	14.8		6.4	0	8	01	6
17	15.0	14.1	23.6	10.8	9.8	17.0	14.8		3.4	0	8	02	5
18	18.2	15.5	23.0	13.5	9.5	17.0	14.8		2.3	0	7	03	7
19	21.3	17.2	26.8	10.9	6.5	16.9	14.9		11.7	0	1	01	6
20	21.3	17.3	25.3	12.0	8.9	17.1	15.0		11.5	0	0	02	7
21	16.0	15.5	24.4	10.2	6.3	17.3	15.1	Tr	8.3	0	9	45	3
22	16.6	16.4	20.0	10.5	7.0	17.3	15.1		0.1	0	8	50	5
23	16.6	15.5	20.1	14.6	13.0	17.3	15.2		0.0	0	8	03	5
24	16.5	15.9	17.5	15.5	13.5	17.3	15.2		0.0	0	9	43	4
25	17.5	15.0	21.1	12.4	9.1	17.0	15.3		10.1	0	4	02	7
26	14.6	12.5	22.5	5.7	2.0	16.8	15.3		10.6	0	4	02	6
27	19.4	17.0	23.8	10.0	6.1	17.0	15.3		5.0	0	4	02	6
28	17.9	14.8	21.7	10.7	6.6	17.0	15.3	1.2	6.3	0	5	03	7
29	16.5	12.5	20.7	11.5	7.1	16.8	15.3		10.0	0	3	03	7
30	16.7	13.0	20.3	12.4	7.2	16.3	15.3	Tr	6.1	0	6	01	7
31	18.8	14.4	21.9	13.3	12.5	16.4	15.3	10.6	6.7	0	4	02	7
MONTH	16.6	14.3	20.9	10.8	7.55	16.4	14.9	55.7	165.1		5.7		
AVERAGE			19.0	10.2				68.8	146.9				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
55.7	80.9 %	165.1 hrs	112%	35.8%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	17	05	Cloudy with sunny intervals
2	09	05	Rain
3	05	06	Rain
4	04	05	Rain, becoming dry and cloudy
5	03	05	Cloudy dry day with sunny intervals
6	21	03	Cloudy with showers
7	01	06	Cloudy with showers and sunny intervals
8	01	06	Cloudy dry day with sunny intervals
9	34	02	Bright and sunny becoming cloudy but remaining dry
10	CALM		Bright and sunny
11	03	02	Bright and sunny
12	CALM		Bright and sunny
13	19	06	Mist at first becoming warm and sunny
14	CALM		Warm and sunny becoming cloudy with some rain showers
15	05	03	Warm and sunny becoming cloudy with sunny spells
16	05	02	Cloudy with morning mist clearing to become generally sunny
17	21	03	Cloudy with morning mist clearing to give sunny periods
18	22	04	Cloudy, warm, dry day
19	20	05	Bright and sunny, warm dry day
20	19	03	Bright and sunny, warm dry day
21	08	01	Fog at first, becoming brighter, warm, dry and sunny
22	06	02	Cloudy, slight drizzle
23	07	03	Misty at first, cloudy day
24	05	07	Fog at first, has become thinner in past hour
25	05	06	Bright and sunny day. Warm and dry
26	10	02	Bright and sunny, warm, dry day
27	33	01	Cloudy with sunny periods, continuing dry and warm
28	25	08	Cloudy with sunny periods. Showers late evening
29	30	12	Bright and sunny, cloudy at times with moderate W breeze
30	26	18	Cloudy with moderate W to SW breeze. Long sunny periods
31	28	18	Cloudy with moderate W to SW breeze. Long sunny periods
MEAN		4.8	
AVERAGE		5.4	

DAILY OBSERVATIONS AND WEATHER

September 1984

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	17.5	15.4	20.2	12.5	10.8	16.3	15.2	6.6	2.0	1	6	02	7
2	19.9	16.6	22.1	14.5	12.5	16.6	15.2	-	5.5	0	5	02	7
3	18.5	16.2	20.5	15.5	12.8	16.5	15.1	26.7	1.1	0	5	02	7
4	12.6	10.1	14.5	9.6	6.8	15.5	15.2	0.9	8.0	2	6	02	7
5	12.0	9.3	14.6	7.0	4.0	15.0	15.1	0.1	0.9	1	6	02	7
6	14.0	11.1	15.9	4.0	0.5	14.3	15.0		8.1	0	1	01	7
7	14.0	11.5	16.9	2.8	0.3	13.9	14.9		3.4	0	2	02	6
8	14.6	12.1	17.0	7.9	5.0	14.1	14.8	2.1	1.5	0	6	03	7
9	14.1	10.5	16.0	10.6	6.5	14.1	14.6		8.5	0	2	01	7
10	14.0	11.8	15.0	9.5	7.8	13.9	14.5		2.0	0	6	03	6
11	14.8	12.2	17.3	11.0	9.7	13.7	14.4		2.0	0	3	01	7
12	13.0	10.9	17.3	10.5	9.5	13.7	14.2	0.2	0.5	0	8	03	6
13	17.1	15.4	19.2	12.5	10.7	14.1	14.2	3.4	0.7	1	7	02	6
14	16.7	16.0	19.1	12.8	11.0	14.4	14.0	0.1	3.9	1	7	02	6
15	12.2	12.0	14.2	10.7	7.9	14.3	14.0	0.4	0.0	1	8	50	5
16	14.1	13.9	18.0	12.1	11.9	14.4	14.1	14.3	1.1	1	7	02	5
17	12.0	11.7	12.7	11.1	10.5	14.5	14.0	6.1	0.0	2	8	65	5
18	12.1	10.8	17.0	8.6	7.5	14.1	14.0		6.4	2	7	01	6
19	11.0	10.0	14.5	10.0	7.4	14.0	14.0		5.7	1	7	02	6
20	11.5	11.0	16.2	6.0	3.5	13.5	14.0	2.5	6.2	0	3	01	6
21	7.7	6.7	12.1	5.6	3.9	13.3	14.0	10.2	5.4	1	8	03	6
22	8.3	7.6	12.3	5.7	2.9	12.5	13.9	4.1	3.0	1	6	02	7
23	10.2	9.1	15.0	6.8	5.5	12.3	13.8	8.3	2.3	1	6	02	7
24	9.6	9.4	12.4	7.0	6.3	12.2	13.5	2.5	1.3	2	5	02	6
25	10.4	8.5	13.8	6.7	4.5	11.9	13.5	0.4	0.6	1	7	03	6
26	11.0	10.3	16.0	8.8	7.8	12.1	13.3	Tr	3.9	2	6	01	6
27	10.3	9.5	15.9	6.7	4.0	12.2	13.2	Tr	1.1	1	7	03	6
28	14.8	13.0	17.1	10.0	9.5	12.8	13.2	7.7	2.5	1	5	01	6
29	11.9	11.8	17.0	11.4	10.6	13.1	13.0	4.4	3.4	2	8	60	4
30	10.7	9.0	12.5	10.2	13.1	13.0	13.0	1.3	7.8	2	4	01	7
MONTH	13.0	11.4	16.08	9.27	7.3	13.8	14.1	96.3	98.8		5.7		
AVERAGE			16.9	8.5				50.6	126				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
96.3mm	190.3%	98.8 hrs	78.4%	25.9%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	30	06	Overnight rain. Cloudy with sunny intervals. Rain at night
2	27	12	Bright and sunny, west to SW breeze
3	31	09	Cloudy becoming brighter with sunny intervals, heavy rain at night
4	02	08	Cloudy, slight rain at first, becoming brighter, sunny intervals,
5	34	08	Cloudy, slight rain becoming brighter with sunny intervals. rain
6	05	01	Bright and sunny, ground frost, warm, dry day
7	CALM		Bright, with sunny intervals
8	31	08	Cloudy, sunny intervals
9	31	20	Bright and sunny, strong NW wind
10	32	05	Bright at first, becoming cloudy
11	29	08	Cloudy, becoming brighter, sunny intervals
12	CALM		Cloudy with sunny intervals, rain at night
13	21	05	Cloudy, rain at night
14	32	04	Cloudy, becoming brighter with sunny intervals
15	35	06	Cloudy, slight drizzle
16	22	01	Cloudy, becoming brighter, sunny intervals
17	CALM		Rain, clearing by late afternoon
18	33	04	Cloudy, becoming brighter with sunny intervals
19	28	07	Cloudy, becoming brighter with sunny intervals & fresh W wind
20	29	05	Bright and sunny. Rain at night
21	22	05	Bright at first, becoming cloudy, rain
22	23	02	Bright, with sunny intervals and showers
23	35	12	Bright, sunny intervals and showers
24	34	10	Rain, becoming brighter, sunny intervals and showers
25	33	06	Cloudy, sunny intervals
26	35	04	Rain at first, becoming brighter with sunny intervals
27	21	06	Bright at first, becoming cloudy, slight rain at night
28	20	13	Bright at first, becoming cloudy, sunny intervals, rain at night
29	35	02	Rain, becoming brighter with sunny intervals, rain at night
30	31	11	Bright and sunny, fresh NW wind, moderating by late afternoon
MEAN		6.3	
AVERAGE		6.8	

DAILY OBSERVATIONS AND WEATHER

October 1984

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	8.1	7.3	14.5	4.7	1.5	12.3	13.1	Tr	5.6	2	7	03	6
2	6.6	6.5	12.5	1.6	-0.6	11.9	13.0	0.1	3.3	1	9	45	2
3	6.1	5.6	12.6	3.8	1.1	11.1	13.0	1.4	3.5	1	8	02	6
4	8.5	6.8	13.6	4.0	1.0	10.9	12.8	Tr	9.0	1	1	01	6
5	8.5	7.2	14.1	2.5	-1.0	10.6	12.7		5.5	1	2	02	6
6	10.9	8.2	13.4	5.4	2.9	10.6	12.6		4.3	1	3	02	7
7	12.1	9.6	16.2	5.3	1.2	10.5	12.5	5.5	4.7	1	1	02	6
8	16.1	14.6	18.2	8.9	6.1	10.8	12.2	1.0	3.2	2	7	03	6
9	10.1	8.5	14.6	7.5	3.5	11.4	12.2	Tr	8.0	1	4	01	6
10	12.1	10.0	14.5	6.3	2.5	10.9	12.1		7.4	1	4	02	6
11	12.2	10.0	13.0	9.5	6.8	11.0	12.1		1.7	0	4	02	7
12	10.5	9.1	14.5	7.3	4.6	10.8	12.0	2.2	2.6	0	4	02	7
13	14.4	12.2	15.9	10.3	9.6	11.4	12.0	Tr	1.1	1	7	03	6
14	15.3	14.0	19.7	13.3	10.5	11.9	12.0		4.3	1	6	02	7
15	15.0	13.2	19.0	11.0	8.4	12.4	12.0		7.7	1	1	01	6
16	11.0	9.5	14.5	5.0	3.0	12.5	12.0		7.9	1	1	02	5
17	12.0	10.9	13.4	10.5	8.6	12.3	12.1	6.5	0.4	0	8	03	6
18	10.6	8.0	12.1	8.9	5.1	12.3	12.1	2.7	5.9	1	4	01	7
19	11.7	11.1	13.0	8.0	5.9	11.5	12.0	5.2	4.9	1	6	03	6
20	9.6	6.9	13.0	5.0	1.7	10.7	12.0		2.0	1	7	02	7
21	8.9	6.8	15.5	5.1	3.5	10.1	12.0	0.8	4.7	1	2	02	7
22	15.4	14.0	17.9	8.5	6.8	10.3	11.9	2.8	2.3	1	6	03	6
23	10.0	7.0	12.0	6.5	2.5	10.9	11.7	Tr	6.8	1	1	01	6
24	7.5	6.7	11.2	6.3	2.0	10.2	11.7	9.4	0.0	1	7	03	5
25	10.9	10.4	13.1	6.9	6.4	10.4	11.6		4.8	2	6	01	5
26	8.1	6.2	13.0	7.5	4.7	10.2	11.5		2.6	1	6	02	7
27	5.4	4.1	11.1	1.3	-2.1	9.2	11.5	0.9	8.8	1	1	01	6
28	9.1	8.7	13.5	5.1	2.6	9.0	10.3	1.1	0.0	1	7	02	5
29	13.4	13.0	17.5	8.6	6.1	9.5	11.2	Tr	0.3	2	8	03	4
30	12.0	10.7	12.5	10.9	9.0	10.5	11.0	0.2	0.1	1	6	01	6
31	7.5	6.8	13.5	6.5	3.4	10.4	11.0	Tr	5.0	1	3	01	6
MONTH	10.6	9.1	14.3	6.8	4.1	10.9	11.9	39.8	128.4		4.7		
AVERAGE			13.2	5.8				64.3	91.76				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
39.8mm	61.8%	12.8.4hrs	139.9%	39.5%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	17	03	Rain at first, becoming brighter with sunny intervals
2	23	03	Fog at first and frost, clearing to give sunny intervals & showers
3	22	03	Cloudy, becoming brighter with sunny intervals, rain at night
4	20	03	Bright and sunny
5	35	06	Ground frost, bright and sunny
6	31	12	Bright and sunny, becoming cloudy with sunny intervals
7	32	11	Bright and sunny, becoming cloudy at night
8	25	15	Rain at first, clearing, cloudy, strong SW wind, sunny intervals & rain
9	21	03	Bright and sunny
10	24	08	Bright and sunny, dry day
11	33	13	Cloudy at first, becoming brighter with sunny intervals
12	25	02	Cloudy at first, becoming brighter, rain at night
13	19	06	Cloudy, strong west winds, moderating, sunny intervals
14	27	04	Cloudy at first, becoming brighter, sunny, dry warm day
15	CALM		Bright and sunny, warm, dry day
16	25	04	Bright and sunny, mild, dry day
17	CALM		Cloudy dry day, becoming bright late afternoon
18	23	25	Rain. Strong winds, becoming brighter, sunny intervals & showers
19	21	12	Bright, winds moderating, showers
20	27	20	Cloudy, strong W wind with some afternoon sunshine
21	29	12	Bright and sunny, rain at night
22	25	08	Cloudy, rain at first, becoming brighter, sunny intervals, rain at night
23	30	06	Bright and sunny, mild dry day
24	19	03	Cloudy, rain, heavy showers
25	23	04	Cloudy, becoming brighter, sunny intervals in afternoon
26	29	08	Hazy sunshine, colder than of late
27	21	06	Ground frost, bright and sunny dry day
28	20	08	Cloudy, rain
29	19	10	Cloudy, rain, clearing to give a little sunshine
30	20	01	Cloudy, mild day, rain at night
31	20	03	Cloudy, becoming brighter with sunny intervals
MEAN		7.1	
AVERAGE		6.9	

DAILY OBSERVATIONS AND WEATHER

November 1984

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	12.7	11.4	16.0	7.2	4.9	10.3	11.0	Tr	4.8	1	2	02	6
2	10.6	8.7	11.1	9.6	8.5	10.7	11.0	26.6	0.2	1	5	03	6
3	7.0	6.6	8.1	6.1	5.2	10.3	11.0	19.9	0.0	2	8	62	5
4	7.3	6.7	7.9	5.8	4.4	9.5	11.1	0.3	0.3	2	7	62	6
5	3.3	1.8	7.2	0.2	-2.6	9.5	11.1	1.2	5.9	2	2	01	6
6	3.5	3.0	7.5	1.3	-0.1	8.0	10.8	5.1	0.0	2	7	03	6
7	7.5	7.4	10.1	3.4	1.8	8.0	10.8	0.2	0.0	2	8	45	1
8	10.0	9.6	11.9	6.6	3.2	8.5	10.5	3.2	0.0	1	9	03	4
9	7.9	7.6	11.1	6.7	4.5	9.0	10.3	7.7	0.0	2	8	02	5
10	10.2	8.6	13.1	7.5	5.5	9.2	10.3		7.6	1	1	01	7
11	6,5	6.3	11.4	5.4	1.9	9.0	10.3	3.9	0.0	1	8	45	1
12	9.5	8.9	10.1	6.0	5.3	9.2	10.3	10.8	0.0	2	8	63	6
13	7.2	7.0	9.4	6.6	5.8	9.1	10.3	0.3	2.5	2	8	03	5
14	7.9	7.4	8.0	5.5	3.1	8.9	10.2	5.3	0.0	2	8	61	5
15	6.5	6.4	8.0	5.5	3.9	8.7	10.2	4.6	0.0	2	9	43	4
16	6.8	6.5	7.2	5.9	4.9	8.5	10.2	7.6	0.0	2	8	02	5
17	6.0	5.6	6.0	5.4	4.5	8.4	10.1	6.7	0.0	2	8	50	5
18	4.8	4.5	5.6	4.4	3.5	8.0	10.0	13.0	0.0	2	8	62	4
19	4.9	4.5	7.1	3.2	2.8	8.0	10.0	0.2	0.6	2	8	02	5
20	3.7	3.0	9.1	2.2	-1.9	7.5	9.8	3.0	5.2	2	3	01	5
21	6.1	5.9	10.8	3.6	2.5	7.0	9.8	2.0	3.0	2	6	01	6
22	7.8	6.5	9.0	6.0	3.6	7.5	9.5	6.4	0.0	2	4	01	6
23	8.4	6.9	9.8	4.0	0.2	7.2	9.4	0.5	3.1	2	4	02	6
24	7.7	4.9	9.2	6.1	3.1	7.2	9.3		6.3	1	2	02	7
25	6.3	4.6	9.0	5.0	1.5	6.9	9.2	0.3	5.7	1	1	02	6
26	6.1	4.8	8.9	4.3	0.7	6.5	9.1		6.0	1	2	02	7
27	8.7	6.8	10.5	2.5	0.1	6.3	9.0	2.7	0.0	1	8	03	6
28	9.1	8.0	9.5	7.8	5.5	6.3	9.0	Tr	4.8	1	6	01	6
29	7.9	7.3	10.0	6.0	3.1	6.9	8.8		1.1	1	3	01	6
30	7.5	6.5	10.8	7.0	5.6	7.3	8.8	2.8	0.0	1	8	03	6
MONTH	7.31	6.46	9.45	5.23	3.16	8.25	10.04	134.3	57.1		5.9		
AVERAGE			8.9	3.0				56.9	58.8				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
134.3mm	236%	57.1 hrs	97%	22.6%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	20	10	Bright and sunny, dry mild day
2	28	02	Cloudy, rain at night
3	35	24	Rain, heavy continuous
4	35	18	Rain, clearing by late afternoon. Cold night
5	31	04	Ground frost, bright and sunny, with rain at night
6	CALM		Ground frost, cloudy damp day, with rain at night
7	CALM		Fog at first, dull damp day
8	09	04	Cloudy, rain
9	CALM		Cloudy, rain
10	24	02	Bright and sunny, warm dry day
11	22	08	Fog, dull damp day
12	24	01	Rain
13	CALM		Cloudy, becoming brighter with sunny intervals
14	CALM		Cloudy, rain
15	CALM		Fog at first, clearing, dull damp day, rain at night
16	04	02	Cloudy, rain
17	05	06	Rain
18	12	02	Rain
19	CALM		Cloudy, becoming brighter with sunny intervals
20	CALM		Ground frost, bright and sunny
21	28	01	Rain at first, becoming brighter with sunny intervals. Rain at night
22	25	06	Rain
23	22	10	Rain
24	24	14	Bright and sunny, cold dry day
25	24	06	Bright and sunny intervals, rain at night
26	31	06	Bright and sunny
27	22	07	Cloudy, strong SW winds, rain at night
28	24	11	Cloudy, becoming brighter with sunny intervals
29	18	05	Cloudy, becoming brighter
30	18	12	Cloudy, strong S to SW wind
MEAN		5.4	
AVERAGE		8.0	

DAILY OBSERVATIONS AND WEATHER

December 1984

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	5.3	4.9	7.3	3.9	0.0	7.3	8.8	3.5	0.0	1	8	63	4
2	6.2	5.9	7.1	4.5	3.9	7.2	8.6	1.1	0.0	1	9	40	4
3	5.2	5.0	7.9	2.8	0.4	7.2	8.6	1.6	0.0	2	8	53	4
4	7.8	7.7	9.2	5.0	3.8	7.2	8.6	2.0	0.0	2	8	44	4
5	9.1	8.8	12.0	5.2	4.5	7.3	8.6	0.3	1.6	2	8	65	5
6	4.5	3.0	10.4	4.0	0.3	7.3	8.6		5.0	1	2	01	7
7	10.0	7.5	10.9	4.1	0.6	7.0	8.5		0.0	1	7	03	6
8	3.2	2.6	8.3	2.4	-1.6	7.1	8.5	0.4	0.0	1	2	01	5
9	5.1	3.5	9.1	2.6	-0.8	6.4	8.6	Tr	2.2	1	1	01	6
10	9.1	7.0	9.5	4.7	2.0	6.5	8.5		0.5	1	6	03	6
11	3.0	2.3	6.9	0.5	-2.2	5.9	8.3		3.2	1	5	01	6
12	1.0	0.9	4.1	-1.7	-4.5	5.1	8.3	Tr	0.0	1	9	43	3
13	4.0	3.8	6.1	0.5	-0.1	5.1	8.3	0.5	0.0	1	8	40	4
14	6.1	6.0	6.7	3.2	1.9	5.3	8.0	0.1	0.0	1	9	45	3
15	0.8	0.5	2.8	0.2	-1.6	5.3	7.9	Tr	0.0	1	9	45	1
16	0.8	0.5	5.7	-0.1	-1.1	5.2	7.8	0.9	0.0	1	9	45	2
17	3.9	3.0	4.6	0.5	0.2	5.3	7.6	3.5	0.0	1	8	50	6
18	2.5	1.1	7.8	1.4	-1.6	4.7	7.6		4.8	4	2	01	6
19	7.5	6.0	10.0	1.0	-1.9	4.7	7.6	Tr	2.7	4	5	02	6
20	8.6	7.2	9.9	6.4	4.3	5.0	7.3	3.4	2.0	1	7	03	6
21	4.0	2.3	6.3	1.8	-1.2	5.0	7.3	0.1	3.7	4	2	01	6
22	6.1	5.5	12.1	1.9	-1.4	5.5	7.2	0.2	0.0	1	8	60	5
23	12.0	10.7	12.5	5.3	4.1	5.6	7.2	1.8	0.8	1	6	02	6
24	4.0	3.4	5.2	3.3	2.3	6.5	7.1	0.5	2.8	2	8	63	6
25	1.5	1.0	4.2	-0.3	-3.6	5.3	7.2	0.8	0.0	4	7	02	6
26	-1.1	0.0	4.2	-0.6	-5.4	5.5	7.2		4.1	4	1	01	7
27	-3.5	-3.0	1.0	-4.0	-5.5	3.7	7.1		2.0	4	2	48	2
28	-0.9	-1.1	1.1	-3.8	-5.8	3.3	7.0		0.0	4	7	02	4
29	-1.8	-2.0	1.5	-3.3	-4.2	3.0	6.8	2.2	0.0	4	9	49	1
30	1.5	1.4	9.0	-2.1	-2.5	2.9	6.5	0.3	0.0	2	9	45	0
31	4.2	3.0	6.5	1.4	-0.6	3.3	6.4	0.5	6.4	1	2	02	7
MONTH	4.1	3.5	7.0	1.6	-0.5	5.5	7.8	23.9	41.8		6.2		
AVERAGE			6.4	1.0				61.5	41.85				

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	CALM		Cloudy, dull damp day
2	CALM		Fog, rain, fog at night
3	18	08	Rain, dull damp day
4	20	02	Cloudy, rain
5	21	09	Rain at first, becoming brighter with sunny periods
6	25	02	Bright and clear, sunny intervals
7	24	09	Cloudy
8	19	04	Ground, frost, cloudy
9	24	06	Ground frost, bright with sunny intervals
10	23	05	Cloudy, dry day
11	22	02	Ground frost, cloudy, fog at night
12	22	01	Fog, cold damp day
13	16	02	Cloudy, ground frost, dull damp day
14	CALM		Fog, dull, damp day
15	18	01	Fog, dull damp day
16	CALM		Fog, rain at night
17	18	06	Cloudy, slight drizzle, rain and sleet showers
18	21	04	Ground frost, bright and sunny
19	23	05	Ground frost, becoming bright with sunny intervals
20	25	05	Cloudy, becoming brighter with sunny intervals
21	27	11	Ground frost, bright and sunny, rain at night
22	20	02	Cloudy, rain, groundfrost
23	23	16	Cloudy, becoming brighter
24	34	14	Rain at first, becoming brighter, cold at night
25	18	10	Frost, rain, dull day
26	21	02	Frost, bright and sunny
27	CALM		Fog, frost, becoming bright with afternoon sunshine
28	21	03	Frost, cloudy dull day
29	19	07	Frost and fog at night. Cloudy and dull with rain at times
30	CALM		Fog at first. Cloudy dull day
31	30	15	Bright and sunny day
MEAN		4.9	
AVERAGE		9.1	

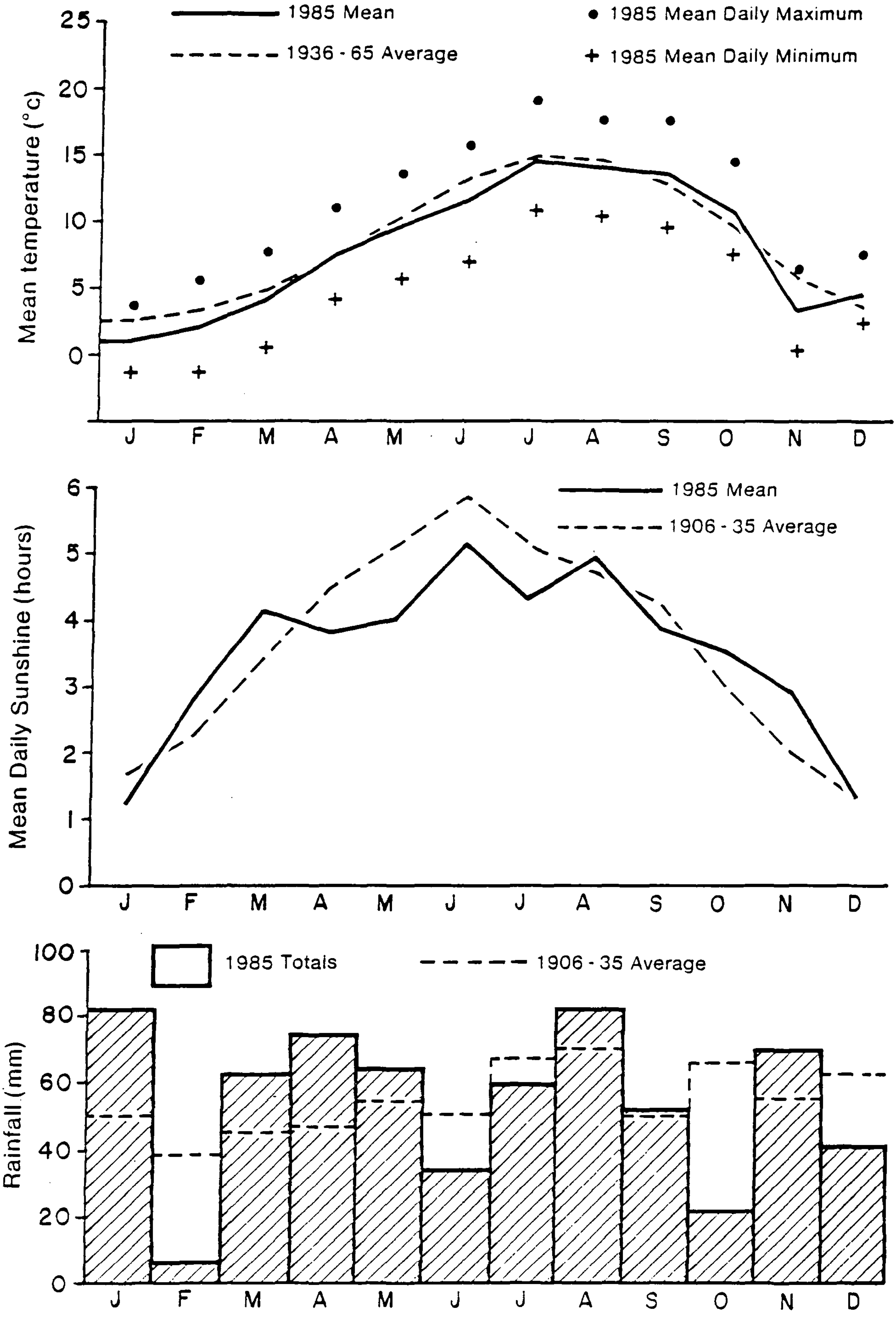
Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
23.9mm	38.9%	41.8hrs	99.8%	18.5%

D a i l y

M e t e o r o l o g i c a l   O b s e r v a t i o n s

1 9 8 5

MEAN TEMPERATURES, SUNSHINE AND RAINFALL AT DURHAM, 1985



DAILY OBSERVATIONS AND WEATHER

DATE	TEMPERATURE °C							RAIN-FALL mm.	SNOW cm. Lying 0900 hours	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
	Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass							
1	3.0	1.9	4.1	2.0	-0.4	3.1	6.2	12.6	-	0.6	1	7	01	7
2	1.5	1.2	3.9	0.8	-1.3	3.1	6.2	3.7	-	2.9	2	8	84	6
3	1.8	1.1	3.2	-0.1	-2.9	3.0	6.0	3.3	-	0.5	1	6	01	6
4	2.4	2.0	4.5	1.0	-1.3	2.9	6.0	3.2	-	1.5	4	6	02	7
5	0.3	0.0	3.1	-0.6	-2.1	3.0	5.9	4.8	2	0.1	3	7	72	4
6	3.1	2.5	4.5	-1.9	-2.1	2.9	5.8	5.5	-	1.2	1	4	01	6
7	-1.3	-2.0	1.0	-2.3	-3.2	2.8	5.8	1.5	2	0.0	7	8	70	6
8	1.0	0.2	2.5	-1.5	-3.0	2.6	5.6	-	3	2.3	7	7	01	6
9	1.8	1.1	2.3	-0.4	-2.6	2.6	5.6	2.1	2	0.0	7	7	02	6
10	1.4	1.0	3.0	0.4	-2.6	2.6	5.5	0.1	1	2.4	2	3	01	6
11	-0.3	-1.5	4.1	-1.0	-4.3	2.5	5.5	-	1	5.0	2	4	02	6
12	-2.7	-3.2	2.1	-4.8	-7.6	2.3	5.4	3.2	1	0.0	2	4	02	6
13	0.5	0.3	0.5	-2.9	-4.0	2.0	5.3	6.6	1	0.0	3	8	71	3
14	-0.5	-1.0	2.1	-2.3	-2.5	2.0	5.2	2.5	6	0.0	7	8	70	5
15	0.6	-0.3	0.9	-1.0	-2.2	2.0	5.2	4.3	7	0.5	7	8	70	5
16	1.0	0.2	1.0	-1.6	-1.8	1.9	5.0	6.5	10	0.0	7	8	70	5
17	-2.0	-2.4	2.0	-2.6	-2.0	1.8	5.0	-	13	0.0	7	8	70	3
18	1.9	0.6	2.5	-4.0	-4.1	2.2	5.0	-	10	0.0	7	8	01	6
19	0.8	0.3	2.0	0.2	-1.4	2.0	5.0	-	10	0.0	7	8	02	6
20	-6.1	-6.2	2.0	-6.8	-7.5	2.0	4.9	2.6	10	0.0	7	9	45	1
21	2.0	1.9	4.2	-6.8	-7.2	2.0	4.9	9.0	6	0.0	7	8	63	5
22	2.9	1.1	3.3	1.3	-0.4	1.8	4.8	-	3	2.7	6	3	01	6
23	-0.9	-1.6	1.9	-2.2	-4.6	1.9	4.8	-	-	7.0	1	1	01	6
24	0.7	0.6	1.7	-1.3	-4.1	1.8	4.5	4.2	-	0.0	1	6	03	6
25	0.2	-0.2	1.1	-1.1	-1.8	1.7	4.5	0.8	5	0.0	7	8	02	5
26	-0.5	-1.6	0.0	-1.6	-4.6	1.6	4.5	-	3	6.9	7	2	01	6
27	-4.9	-5.2	3.0	-6.9	-7.1	1.5	4.4	2.6	3	0.2	7	6	03	6
28	2.8	2.5	7.2	-3.5	-5.5	1.5	4.5	1.4		1.4	1	8	63	5
29	7.2	6.4	8.5	1.4	-1.7	1.8	4.4	0.1		0.0	1	4	01	6
30	5.2	4.3	8.8	2.5	-1.4	1.5	4.3	1.4		0.0	1	5	03	5
31	5.1	4.2	11.5	4.2	1.8	1.4	4.2	-		1.8	2	3	02	6
MONTH	0.9	0.3	3.3	-1.4	-3.1	2.2	5.2	82		37		6.1		
AVERAGE			5.3	-0.1				49.3		50.2				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
82 mm	116	37	73.7	15

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	33	18	Cloudy, ground frost, sunny intervals, w. sleet & snow showers.
2	35	06	Groundfrost, sleet & snow showers & sunny intervals.
3	33	06	Frost, slight snow. Cloudy, rain & sleet showers.
4	05	03	Groundfrost, cloudy becoming brighter, rain at night.
5	34	01	Cloudy, snow, sleet & snow showers
5	34	10	Frost, sunny intervals, snow at night
7	07	03	Snow, cloudy, snow showers
8	32	07	Cloudy, frost, snow covering ground completely, becoming brighter w. sunny intervals.
9.	33	05	Cloudy, showers
10	30	07	Groundfrost. Showers. Cloudy becoming brighter w. sunny intervals.
11	CALM		Frost, calm, bright & sunny
12	CALM		Frost, calm cold day
13	14	02	Snow
14	02	02	Slight snow showers
15	09	05	Snow showers & sunny intervals. Heavy snow at night
16	09	05	Cloudy, snow showers
17	20	03	Snow showers at first, cold day
18	06	05	Cloudy
19	CALM		Cloudy calm day
20	CALM		Freezing fog
21	13	10	Rain, frost
22	23	18	Ground frost, sunny intervals
23	29	14	Frost, cold but bright day
24	27	10	Cloudy, snow showers, snow covering ground completely.
25	35	01	Cloudy
26	30	11	Bright & sunny, frost, snow showers.
27	20	02	Cloudy, snow showers, frost.
28	19	07	Rain, frost, becoming brighter with sunny intervals.
29	22	03	Cloudy, groundfrost
30	24	04	Cloudy, groundfrost
31	28	16	Cloudy, becoming brighter with sunny intervals.
MEAN	= 5.9 knots		
AVERAGE	9.6 Knots		

FEBRUARY

DAILY OBSERVATIONS AND WEATHER

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SNOW cm. Lying 0900 hours	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	9.5	6.5	10.0	4.5	2.5	3.3	4.4	-		0.5	1	3	02	6
2	7.5	5.5	9.5	5.4	3.4	3.8	4.4	0.1		3.7	1	4	02	6
3	4.1	3.4	8.0	2.6	1.1	3.9	4.1	0.2		0.0	1	7	03	5
4	6.4	5.5	8.0	3.5	2.5	4.4	4.5	-		0.0	1	6	01	6
5	5.1	4.1	6.8	4.4	3.1	4.6	4.7	-		0.5	1	8	03	5
6	6.4	6.2	6.4	-1.3	-4.8	4.1	4.8	0.1		0.0	1	9	43	4
7	2.3	0.8	3.1	1.0	-1.1	3.8	4.8	1.1		0.0	1	7	01	6
8	2.2	0.5	2.1	0.1	-1.0	3.5	4.9	-		0.0	1	6	02	6
9	-0.9	-1.2	-0.5	-1.6	-2.5	2.9	5.0	-		0.1	1	6	02	5
10	-1.9	-2.0	-0.3	-2.6	-4.1	2.5	4.9	0.3		1.7	1	7	72	5
11	-2.3	-2.3	-0.8	-4.1	-5.5	2.4	4.9	-	1	0.8	2	8	03	6
12	-2.8	-3.2	1.9	-4.5	-9.3	2.0	4.7	-	1	6.2	2	2	01	6
13	0.3	0.1	1.0	-6.5	-8.6	2.0	4.7	2.0		0.3	1	6	03	6
14	0.1	0.0	3.5	-2.6	-8.0	1.8	4.5	-	2	4.0	7	6	70	6
15	-3.7	-4.0	3.7	-7.7	-10.6	1.6	4.4	-		8.7	2	1	01	6
16	-2.5	-2.8	5.9	-6.6	- 8.9	1.5	4.3	-		7.2	1	1	02	5
17	0.0	-0.6	2.0	-5.1	-8.5	1.4	4.2	-		3.3	1	1	02	5
18	-1.8	-2.0	0.2	-5.0	-7.5	1.3	4.2	-		4.5	1	6	03	5
19	-2.3	-2.6	4.1	-4.4	-5.7	1.3	4.2	-		0.0	1	7	03	5
20	3.5	2.6	10.0	-2.5	-2.8	1.3	4.2	-		7.9	4	3	01	6
21	-1.9	-2.1	7.0	-5.1	-7.0	1.2	4.1	-		3.1	4	9	45	0
22	0.0	-0.4	7.9	-2.7	-4.1	1.1	3.8	-		3.5	4	7	40	3
23	7.9	6.8	9.9	-0.5	-1.4	1.3	3.8	-		0.0	1	6	02	6
24	7.8	6.2	10.5	5.4	1.4	2.1	3.7	-		8.6	1	2	01	5
25	2.8	1.7	7.2	-0.2	-2.5	2.7	3.8	1.3		0.4	1	5	02	5
26	3.9	2.5	10.7	-1.2	-3.5	2.7	4.5	-		5.6	1	2	01	5
27	1.1	0.8	9.9	-1.5	-4.6	3.0	3.9	-		7.4	4	2	02	5
28	4.0	4.0	5.0	1.1	-0.2	3.8	4.0	0.6		00	1	9	43	1
MONTH	1.96	1.21	5.5	-1.4	-3.5	2.5	4.4	5.7		78		5.2		
AVERAGE			6.0	0.1				38.1		64				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
5.7	15%	78	121.6%	29%

FEBRUARY

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	29	26	Cloudy, strong W. to NW wind, sunny intervals.
2	30	24	Cloudy, becoming brighter
3	20	06	Cloudy, slight rain
4	24	02	Cloudy
5	18	02	Cloudy, becoming brighter with sunny intervals
6	CALM		Fog, frost, cloudy day
7	15	04	Cloudy, groundfrost, rain
8	11	16	Cloudy, strong east to SE winds, snow showers
9	11	16	Cloudy, cold, snow showers
10	11	14	Cloudy, snow showers, cold
11	15	10	Cloudy, cold day
12	CALM		Calm, bright & sunny, frost, cold day
13	10	04	Cloudy, sunny interval
14	05	03	Snow showers, becoming bright & sunny, cold day
15	32	01	Frost, bright & sunny, cold day
16	CALM		Frost, bright & sunny, cold day
17	20	01	Frost, cold, with sunny intervals
18	21	08	Frost, cloudy, becoming brighter with sunny intervals.
19	22	03	Frost, cloudy
20	33	01	Frost, bright & sunny
21	22	03	Freezing fog, clearing to give sunny intervals, fog at night
22	22	03	Frost, fog at a distance, becoming brighter w. sunny intervals
23	24	12	Frost, cloudy
24	24	02	Bright & sunny, mild
25	CALM		Frost, becoming brighter at first, cloudy, rain
26	CALM		Frost, bright & sunny
27	CALM		Frost, bright & sunny
28	19	03	Fog, cloudy-rain at night
MEAN	5.85 knots.		
AVERAGE	8.4 Knots		

DAILY OBSERVATIONS AND WEATHER

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SNOW cm. Lying 0900 hours	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	1.8	1.4	2.4	1.0	0.3	3.9	4.0	3.6		0.0	1	8	03	5
2	1.6	1.5	3.5	0.0	-1.0	3.5	4.0	0.1		0.0	1	7	02	5
3	3.4	3.1	7.2	0.9	-2.3	3.5	4.3	3.1		0.0	1	7	60	4
4	5.8	4.5	7.5	3.0	2.7	3.5	4.3	0.1		0.7	1	6	01	6
5	6.7	4.7	10.7	3.4	0.1	4.1	4.4			8.4	1	5	01	7
6	2.8	1.7	10.5	-0.5	-4.0	4.1	4.4			9.0	1	6	02	5
7	7.9	6.3	12.5	2.6	2.5	4.7	4.5			7.6	1	3	02	6
8	5.2	3.5	10.0	-1.5	-5.2	4.8	4.7			2.7	1	3	02	6
9	7.2	5.1	9.7	4.6	2.1	5.2	4.8			0.3	1	7	03	6
10	9.1	8.0	9.9	5.5	1.2	5.3	4.9	3.7		3.0	1	5	02	6
11	5.3	4.0	10.3	-1.9	-5.3	5.0	4.6	tr		8.8	1	2	01	6
12	4.2	2.5	9.8	-2.5	-6.4	5.3	5.1	tr		8.1	1	2	02	6
13	5.5	3.6	7.6	3.2	-1.5	5.4	5.2			0.6	1	6	03	6
14	4.7	2.1	7.9	0.5	-2.4	5.3	5.1			8.4	1	2	01	7
15	3.5	1.4	5.5	-3.0	-6.9	5.4	5.1	7.1		4.4	4	3	02	7
16	0.6	0.1	3.8	-1.7	-6.0	5.4	5.1	0.2	6	6.3	7	8	72	5
17	2.4	0.4	6.2	-3.8	-7.6	5.4	5.1	1.4		6.6	2	4	02	6
18	2.8	0.1	6.5	-4.1	-7.7	5.4	5.2	tr		9.0	1	2	01	5
19	2.3	0.1	4.6	-2.0	-6.2	5.4	5.1	2.0		6.9	1	2	02	7
20	0.3	-0.3	3.5	-1.6	-6.0	5.4	5.1	tr	2	1.3	2	8	71	4
21	2.1	0.2	4.1	-2.9	-5.9	5.4	5.1	3.2		1.7	1	4	03	5
22	4.0	3.6	5.1	1.7	-1.0	5.4	4.9	6.5		0.0	2	8	61	5
23	5.1	4.9	5.0	3.1	2.0	5.4	4.8	9.0		0.0	2	8	62	2
24	3.6	3.3	6.5	2.5	1.6	5.4	4.8	1.1		0.0	2	7	60	5
25	6.0	3.9	9.4	0.7	-2.9	5.4	4.8			9.7	2	3	01	7
26	3.2	2.6	9.5	2.5	-5.8	5.4	4.8	1.4		7.0	1	8	03	5
27	2.5	0.6	6.8	1.4	-1.0	5.4	4.8	tr		6.1	1	8	02	6
28	4.5	2.8	8.5	-0.3	-3.8	5.4	5.0	2.8		3.4	1	8	02	6
29	2.2	2.0	10.4	0.1	-1.1	5.4	5.0	9.5		0.0	2	8	63	5
30	10.4	8.8	12.1	1.8	1.3	5.7	5.2	0.9		3.6	2	6	02	6
31	10.3	7.6	12.0	6.6	4.6	5.9	5.4	6.4		5.0	1	4	01	6
MONTH	4.4	3.0	7.7	0.6	-0.03	5.0	4.8	62.1		128.6		5.4		
AVERAGE			8.6	1.3				44.9		106				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
62.1	138	128.6	121	35

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	13	04	Cloudy, rain, sleet & snow showers
2	23	01	Cloudy, ground frost, rain
3	22	04	Cloudy, ground frost, rain
4	23	10	Cloudy becoming brighter, showers
5	26	03	Bright & sunny
6	24	04	Frost, bright & sunny dry day
7	31	02	Bright and sunny dry day
8	22	04	Frost, bright and sunny
9	23	10	Bright at first, becoming cloudy
10	28	05	Cloudy, rain clearing by early afternoon to give sunny intervals
11	33	01	Frost, bright and sunny
12	26	03	Frost, bright and sunny
13	34	05	Bright at first becoming cloudy ground frost
14	33	09	Ground frost, bright & sunny
15	29	04	Frost, bright & sunny, slight snow showers
16	05	05	Snow, cold day
17	31	05	Frost, bright & sunny. Slight snow showers
18	CALM		Frost, slight snow showers, bright & sunny cold day
19	15	04	Frost, bright & sunny
20	CALM		Snow showers
21	12	06	Frost becoming bright w. sunny intervals, rain at night
22	09	06	Rain, ground frost
23	05	10	Rain, heavy showers
24	CALM		Rain
25	24	06	Bright & sunny, ground frost
26	04	01	Bright & sunny at first, becoming cloud, ground frost, sunny intervals, rain at night
27	35	10	Cloudy, ground frost, slight snow shower, becoming brighter, sunny intervals.
28	33	05	Cloudy, frost, becoming bright w. sunny intervals.
29	07	01	Rain, ground frost
30	22	10	Rain, becoming brighter w. sunny intervals.
31	25	14	Bright & sunny, mild.
MEAN	= 4.9 knots		
AVERAGE	7.3 Knots		

DAILY OBSERVATIONS AND WEATHER

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SNOW cm. Lying 0900 hours	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	12.0	10.6	15.1	6.3	5.4	6.5	5.4	0.2		0.6	2	7	01	6
2	10.2	7.5	14.2	7.8	5.2	7.0	5.5	0.7		5.8	1	5	01	7
3	11.9	11.2	12.5	6.5	5.5	7.8	5.8	2.3		0.0	1	7	50	6
4	10.4	9.0	11.9	7.4	3.4	7.9	6.0	7.0		0.7	1	7	01	6
5	10.0	8.5	13.8	5.8	2.2	7.9	6.1	2.1		4.3	1	4	03	6
6	9.8	7.6	11.6	5.5	4.1	8.3	6.3	-		5.7	1	4	03	7
7	8.6	7.0	10.2	3.1	-1.4	8.0	6.5	13.2		2.5	1	2	02	6
8	7.0	6.9	9.3	5.5	4.7	7.8	6.6	2.4		0.5	2	8	61	6
9	5.4	4.9	5.7	4.2	3.0	7.8	6.7	5.8		0.0	2	8	61	6
10	4.5	3.8	6.2	3.1	2.3	7.8	6.6	4.1		0.0	2	8	60	5
11	5.4	4.8	8.5	4.1	2.5	7.3	6.8	9.0		0.0	2	8	63	6
12	8.5	5.8	11.0	2.6	-1.1	7.0	6.8	1.7		6.9	2	1	01	7
13	7.4	5.0	8.6	3.5	0.1	7.0	6.8	0.1		3.9	2	6	03	7
14	8.0	5.9	11.9	4.4	0.6	6.6	6.8	12.5		5.1	2	6	02	7
15	8.6	5.7	12.5	2.3	-2.5	6.6	6.9	tr		3.4	2	6	02	6
16	11.9	10.0	14.5	8.4	5.9	7.4	7.0	-		2.2	2	6	02	6
17	12.4	10.2	15.2	8.7	5.3	8.2	7.0	-		2.2	1	6	02	6
18	12.4	9.8	16.1	4.8	1.8	8.7	7.1	-		10.9	1	3	01	7
19	11.6	9.3	12.0	8.9	5.9	8.7	7.1	-		3.6	1	5	02	6
20	5.3	3.8	7.5	2.2	-0.2	8.7	7.5	4.0		4.3	0	7	03	6
21	6.2	5.3	7.0	4.0	2.5	8.3	7.5	tr		0.0	1	7	02	5
22	6.2	4.5	10.6	4.1	2.3	7.8	7.5	1.0		4.7	1	8	03	6
23	5.6	3.2	10.1	3.1	1.1	8.5	7.5	-		7.4	1	7	02	6
24	10.0	6.8	15.2	-2.5	-6.2	8.1	7.6	0.4		12.5	1	1	01	7
25	3.4	1.4	8.1	2.0	0.1	9.0	7.8	-		7.6	1	6	03	7
26	7.4	4.5	11.8	-1.7	-4.5	8.5	7.8	1.0		2.2	1	5	01	7
27	6.1	3.1	6.3	1.5	-1.1	8.4	8.0	0.8		8.0	1	4	02	7
28	5.4	2.1	6.7	-0.6	-4.2	7.8	8.0	4.0		2.7	0	5	03	6
29	3.9	3.6	11.1	-0.1	-1.4	7.4	7.9	2.4		0.0	2	8	03	5
30	11.0	10.3	15.0	3.9	3.6	8.9	7.9	0.1		6.6	2	7	01	6
MONTH	8.2	6.4	11.00	4.0	1.5	7.9	7.0	74.8		114.3		5.7		
AVERAGE			11.8	3.3				45.9		134.1				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
74.8 mm	163%	114.3 hrs	85%	27%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	24	06	Cloudy, sunny intervals.
2	32	11	Bright & sunny, becoming increasingly cloudy. Windy at night.
3	22	06	Cloudy, mild, rain
4	18	03	Cloudy with a little sunshine, rain late afternoon & evening
5	19	08	Bright and sunny becoming cloudy
6	23	09	Bright and sunny becoming cloudy
7	17	02	Bright and sunny at first, becoming cloudy w. rain.
8	33	02	Rain becoming dry with a little sunshine late afternoon
9	33	05	Rain
10	10	02	Rain. Cold day
11	19	10	Rain
12	30	08	Bright & sunny, ground frost, rain at night
13	24	13	Bright & sunny, strong s.w. wind, rain.
14	35	16	Bright & sunny, hail storm afternoon
15	CALM		Bright & sunny, becoming cloudy w. sunny intervals.
16	23	05	Cloudy, sunny intervals
17	CALM		Cloudy, becoming brighter
18	21	05	Bright & sunny, warm dry day
19	27	11	Cloudy, strong west wind, sunny intervals
20	34	08	Cloudy, slight ground frost, sunny intervals, rain at night
21	02	14	Cloudy, cool day
22	05	04	Cloudy, becoming brighter w. sunny intervals, rain at night
23	06	10	Cloudy, becoming brighter w. sunny intervals, frost at night
24	32	10	Frost, bright and sunny, warm dry day
25	04	08	Cloudy, becoming brighter w. sunny intervals, cold N.E. wind.
26	27	06	Cloudy, frost, becoming bright w. sunny intervals.
27	33	16	Ground frost, bright & sunny
28	34	10	Frost, bright at first, becoming cloudy w. snow showers
29	25	02	Frost, cloudy, rain at night
30	31	03	Cloudy, mild with sunny intervals, rain at night.
MEAN	7.1 knots		
AVERAGE	8.1 Knots		

DAILY OBSERVATIONS AND WEATHER

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SNOW cm. Lying 0900 hours	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	9.4	6.4	12.8	3.3	0.1	8.7	7.9	3.8		11.9	1	3	01	7
2	7.1	5.2	10.4	2.1	-1.4	8.9	7.9	tr		4.2	1	7	03	6
3	6.9	5.0	9.4	5.2	2.7	8.9	7.9	tr		0.7	1	8	02	6
4	7.6	5.0	8.4	4.5	3.0	8.8	8.0			0.0	1	8	01	6
5	6.8	5.7	9.0	4.3	3.4	8.8	8.0	0.2		0.0	1	8	02	5
6	8.5	6.8	14.6	3.2	-1.4	8.4	8.0			9.1	1	7	02	7
7	11.9	8.1	15.6	1.0	-2.8	8.4	8.0	7.2		12.1	0	1	01	7
8	10.8	9.6	12.4	7.5	6.3	10.1	8.2	0.1		0.0	2	8	03	6
9	11.4	9.9	12.8	6.7	5.9	10.3	8.4	1.8		0.1	2	8	02	5
10	8.7	7.7	12.0	5.9	4.6	10.1	8.4	tr		4.4	2	8	02	5
11	7.7	5.9	9.3	6.0	5.0	10.1	8.4	tr		0.0	1	8	02	5
12	7.2	5.6	11.5	3.3	-1.2	9.9	8.6	1.1		4.2	1	6	02	6
13	7.6	7.5	8.9	5.3	4.5	10.4	8.7	5.9		0.0	2	8	64	5
14	7.8	7.4	9.2	6.4	5.3	9.9	9.0	17.3		0.0	2	8	65	5
15	9.0	8.9	15.1	6.5	5.2	9.0	8.9	0.2		0.2	2	8	65	6
16	15.0	12.2	17.8	7.9	3.6	9.7	9.0			7.3	1	4	01	7
17	15.2	12.7	18.6	5.5	2.5	10.9	9.0	2.1		6.7	1	4	02	7
18	10.5	10.3	13.6	9.5	8.2	11.8	9.0	6.7		1.0	2	8	62	3
19	8.1	8.0	13.7	6.6	5.6	11.8	9.4	1.1		0.0	1	8	50	4
20	13.5	10.5	14.0	5.9	3.0	10.9	9.5	0.5		5.5	1	5	01	6
21	7.6	6.6	9.5	5.7	4.4	11.1	9.5	0.4		0.0	1	8	03	6
22	7.0	6.4	10.5	5.6	4.6	10.8	9.5	tr		0.0	1	8	02	6
23	10.3	8.1	12.7	6.1	4.6	10.7	9.6	6.2		1.8	1	6	01	6
24	11.6	10.6	14.4	9.4	8.0	11.2	9.6	0.9		5.7	2	8	03	6
25	12.1	11.1	16.8	9.5	6.1	11.3	9.8	1.7		0.8	1	6	01	6
26	14.1	13.2	21.5	11.6	9.6	11.6	9.9	tr		4.0	1	7	03	5
27	16.9	15.0	19.3	10.6	8.2	12.5	10.0	6.7		1.4	0	6	01	6
28	12.4	7.9	15.2	6.3	3.0	12.6	10.2			13.1	0	1	01	7
29	15.0	11.4	16.0	4.5	-0.1	12.6	10.2			5.9	0	3	02	7
30	14.5	10.6	18.1	2.9	0.4	12.2	10.5			12.7	0	0	02	7
31	15.1	10.0	18.0	3.6	0.1	12.8	10.5			12.7	0	2	02	7
MONTH	10.6°C	8.7	13.6	5.9	3.6	10.5	9.0	63.9		125.5		6		
AVERAGE			14.8	5.5				54.1		159.%				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
63.9 mm	118%	125.5 hrs	78.5	25

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	31	15	Bright & sunny. Strong NW wind. Rain by afternoon & night
2	35	08	Bright at first, becoming cloudy, groundfrost
3	01	08	Cloudy day
4	CALM		Cloudy, calm day
5	10	02	Cloudy, dull day
6	16	05	Cloudy, bright with sunny intervals.
7	02	05	Ground frost, bright & sunny, warm dry day, overnight rain
8	04	06	Cloudy
9	35	05	Cloudy, rain at night
10	02	02	Cloudy, becoming brighter with sunny intervals
11	07	06	Cloudy
12	04	08	Groundfrost, cloudy, becoming brighter w. sunny intervals.
13	06	06	Cloudy, rain heavy at times
14	01	05	Rain, thunderstorm at night
15	18	07	Rain at first, dull damp day
16	CALM		Bright & sunny, warm dry day
17	20	03	Bright & sunny, warm dry day
18	21	01	Rain, mild day
19	06	06	Drizzle, cloudy day, rain at night
20	05	04	Bright & sunny, showers late afternoon
21	04	04	Cloudy, rain at night
22	01	01	Cloudy, showers
23	13	02	Bright & sunny, becoming cloudy, rain at night
24	21	09	Rain, cloudy
25	23	04	Cloudy, rain, sunny intervals
26	20	05	Cloudy, becoming brighter, warm dry day
27	19	04	Cloudy, few bright intervals, showers later, some quite heavy
28	24	08	Bright and sunny, dry day
29	18	03	Bright & sunny, slight groundfrost, becoming cloudy with sunny intervals.
30	21	03	Bright & sunny, warm dry day
31	23	01	Bright & sunny
MEAN	4.67 knots		
AVERAGE	7.0 Knots		

JUNE 1985

DAILY OBSERVATIONS AND WEATHER

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SNOW cm. Lying 0900 hours	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	16.5	11.4	18.2	2.8	-0.8	13.3	10.7			13.7	0	1	02	7
2	15.8	11.8	18.5	2.1	-1.6	13.6	10.9			12.9	0	1	01	5
3	17.1	12.4	19.0	2.4	0.1	13.9	11.0			13.6	0	1	02	6
4	14.0	12.9	17.3	8.6	5.3	14.5	11.3	0.1		6.3	0	6	03	6
5	11.2	10.4	11.7	9.2	8.9	14.7	11.4	0.9		0.0	0	8	03	6
6	9.4	8.0	12.1	7.3	6.9	13.8	11.6	0.4		1.2	1	8	03	6
7	8.8	6.1	12.4	4.3	2.8	13.3	11.7	tr		2.6	1	8	02	6
8	11.9	7.7	14.6	2.6	0.6	12.7	11.7	5.9		6.9	0	3	01	7
9	11.6	10.2	15.0	7.3	6.9	13.1	11.6			4.7	1	6	03	7
10	14.3	10.3	15.4	6.3	4.5	13.0	11.5	1.3		6.3	0	5	02	6
11	14.1	12.3	15.0	8.0	5.5	13.0	11.7	4.5		0.6	0	7	03	6
12	9.6	7.8	15.6	6.3	5.5	12.8	11.7	6.4		4.0	1	7	62	6
13	11.8	8.8	13.2	6.7	5.0	12.8	11.7	4.3		4.3	1	7	03	6
14	11.0	8.0	13.6	5.8	4.6	12.8	11.6	0.8		3.6	1	5	01	6
15	10.9	8.3	15.5	4.4	1.6	13.0	11.6	0.2		1.8	1	6	02	7
16	11.5	10.4	15.6	4.6	1.0	12.8	11.6			9.2	0	6	02	6
17	15.6	11.3	16.2	4.3	2.1	12.8	11.6	0.5		4.4	0	5	01	6
18	14.0	10.6	16.9	9.4	5.4	13.4	11.7	2.0		3.4	0	7	03	6
19	14.5	11.6	16.5	5.9	4.1	13.8	11.8			8.5	1	4	01	7
20	12.4	10.5	18.1	6.2	4.0	13.8	11.9	1.2		6.5	1	3	01	6
21	10.9	10.3	14.0	9.0	7.4	14.3	12.0	1.2		0.0	2	8	63	5
22	14.0	12.9	15.6	10.6	10.4	13.7	12.0	1.5		0.1	1	8	02	6
23	13.9	12.4	14.7	11.6	11.3	13.9	12.2	1.1		0.6	1	7	02	7
24	14.6	11.7	15.6	10.5	9.9	13.9	12.2			4.0	1	6	02	6
25	14.9	10.6	17.8	7.7	4.5	13.7	12.4	tr		9.7	0	4	01	6
26	12.9	11.2	18.1	6.7	4.9	13.7	12.4	2.1		3.8	0	7	03	6
27	14.2	11.8	18.0	10.2	8.9	14.0	12.4	0.2		6.3	1	7	02	6
28	11.6	9.8	15.6	10.5	9.4	14.0	12.4			4.0	1	7	62	6
29	15.1	10.5	17.6	7.2	2.5	13.8	12.4			7.4	0	4	01	6
30	16.8	13.4	19.1	7.3	4.5	14.1	12.5	tr		3.3	0	5	03	7
MONTH	13.2	10.5	15.9	6.9	4.9	13.5	11.8	34.6		153.7		5.6		
AVERAGE			17.9	8.5				50		174.6				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
34.6 mm	69%	153.7 hrs	88%	30%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	07	01	Bright & Sunny, warm dry day
2	19	01	Bright & sunny, warm dry day
3	14	02	Bright & sunny, warm dry day
4	06	01	Cloudy, becoming brighter w. sunny intervals, rain at night
5	05	03	Cloudy, rain at night
6	06	05	Rain, becoming brighter with sunny intervals
7	02	05	Cloudy, sunny intervals, light rain
8	30	04	Bright & sunny, rain at night
9	32	05	Cloudy, becoming bright with sunny intervals
10	33	05	Bright & sunny, becoming cloudy w. sunny intervals, rain at night
11	27	05	Cloudy, sunny intervals, rain at night
12	33	06	Bright at first, becoming cloudy, rain
13	33	06	Bright & sunny, becoming cloudy, rain
14	35	02	Cloudy, becoming brighter w. sunny intervals, rain
15	CALM		Cloudy, sunny intervals & showers
16	06	02	Bright & sunny, becoming cloudy w. sunny intervals
17	20	01	Bright & sunny, becoming cloudy, showers
18	32	06	Bright at first, cloudy w. rain in evening
19	14	01	Bright & sunny
20	19	02	Cloudy at first, becoming brighter, warm & sunny
21	17	06	Rain, cloudy
22	15	04	Cloudy, showers
23	23	10	Cloudy, sunny intervals, rain
24	31	05	Bright at first, becoming cloudy w. sunny intervals
25	26	08	Bright & sunny S. westerly breeze
26	21	03	Bright at first, becoming cloudy, showers, sunny intervals, rain
27	32	08	Cloudy, becoming brighter with sunny intervals
28	29	08	Cloudy, rain, becoming brighter w. sunny intervals
29	32	09	Bright & sunny becoming cloudy w. sunny intervals
30	22	08	Bright & sunny, becoming cloudy
MEAN 4.4 Knots			
AVERAGE 6.3 Knots			

DAILY OBSERVATIONS AND WEATHER

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SNOW cm. Lying 0900 hours	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	16.8	13.6	17.8	12.0	10.0	14.4	12.6	-		4.4	0	7	03	6
2	17.6	14.2	21.5	7.3	3.8	14.1	13.6	-		4.5	0	4	01	7
3	19.4	15.4	23.6	11.9	10.7	15.0	12.8	-		5.5	0	4	02	6
4	19.1	15.4	22.5	11.6	9.8	15.7	12.8	-		11.6	0	2	02	5
5	18.3	16.2	19.2	11.5	8.6	15.7	12.9	2.9		1.7	0	6	03	5
6	14.7	10.8	18.2	10.3	8.5	15.6	13.0	-		11.4	0	4	02	7
7	16.5	11.6	20.6	7.9	3.2	15.4	13.4	1.1		9.8	0	3	02	7
8	15.5	13.9	20.4	10.9	9.5	15.6	13.3	4.0		1.1	1	8	03	7
9	15.4	12.1	19.6	11.0	8.4	15.6	13.3	-		5.2	1	4	01	7
10	17.6	13.9	20.1	8.0	4.3	15.5	13.6	-		7.7	0	4	02	7
11	17.0	14.5	18.5	13.3	10.5	15.7	13.7	tr		0.1	0	8	03	7
12	18.4	15.6	19.6	15.1	13.9	15.5	13.5	0.2		2.0	0	5	01	7
13	13.0	12.3	16.6	10.5	6.4	15.5	13.5	2.0		0.0	1	8	63	5
14	16.6	15.5	17.6	12.1	11.8	15.3	13.6	tr		2.3	1	7	01	6
15	14.1	10.0	16.5	6.8	1.6	14.9	13.6	3.4		3.2	0	6	03	7
16	16.5	12.8	18.3	9.9	8.2	14.5	13.6	-		8.2	1	4	03	7
17	14.5	12.5	18.0	10.5	7.1	14.6	13.5	0.9		0.3	0	8	01	6
18	13.5	10.5	16.6	9.4	5.6	14.3	13.5	1.5		3.3	0	8	01	7
19	12.4	10.8	17.3	10.2	6.5	14.1	13.5	1.8		6.7	1	8	62	6
20	12.0	9.6	17.0	8.5	4.5	14.3	13.5	tr		8.4	1	5	62	7
21	13.4	9.5	18.0	8.1	5.3	14.0	13.5	0.8		9.4	0	5	03	7
22	13.5	13.2	19.4	11.4	9.4	14.4	13.5	1.1		1.1	1	8	62	5
23	14.1	10.4	20.8	8.1	3.7	14.0	13.4	tr		5.8	0	5	03	7
24	20.8	17.5	23.1	14.0	12.1	14.8	13.4	-		4.2	0	4	02	7
25	20.5	18.6	24.1	12.2	8.5	15.4	13.5	0.4		10.2	0	4	02	6
26	14.8	14.8	16.9	12.2	10.8	16.0	13.5	18.0		0.0	1	9	45	4
27	15.0	12.8	17.2	13.5	12.1	15.5	13.6	1.2		4.3	1	5	02	7
28	9.1	8.9	16.5	8.9	4.0	15.1	13.8	10.2		0.0	1	8	50	3
29	14.7	14.5	17.0	12.7	9.2	15.0	13.8	10.0		0.0	2	8	02	5
30	11.9	11.7	18.0	11.4	10.8	15.1	13.8	0.1		2.0	2	8	63	5
31	13.9	12.4	17.9	11.5	10.0	15.2	13.8	-		0.3	1	8	03	5
MONTH	15.5	13.1	19	10.7	8.0	15.0	13.4	59.6		134.7		6.1		
AVERAGE			19.4	10.4				65.8		159.3				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
59.6 mm	90%	134.7 hrs	84%	26%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	30	07	Bright at first, becoming cloudy with sunny intervals
2	20	03	Bright & sunny. Warm, dry day
3	17	04	Bright & sunny. Warm dry day
4	20	05	Bright & sunny
5	CALM		Cloudy, rain at night
6	33	12	Bright & sunny. N.west breeze, dry day.
7	31	07	Bright & sunny. Warm dry day. Rain at night.
8	29	04	Cloudy with sunny intervals, rain at night
9	31	09	Cloudy becoming brighter, with sunny intervals.
10	30	05	Bright & sunny, warm dry day
11	23	11	Cloudy with a S.westerly wind. Showers.
12	25	08	Bright at first, becoming cloudy, strong S.W. wind.
13	06	01	Cloudy, rain.
14	CALM		Cloudy day w. some evening sunshine
15	28	10	Bright & sunny at first, becoming cloudy.
16	28	08	Overnight rain. Bright & sunny
17	19	05	Cloudy day, rain showers during evening.
18	23	13	Cloudy but bright. Sunny intervals.
19	23	07	Cloudy with rain showers and sunny periods.
20	25	06	Bright & sunny.
21	27	10	Bright & sunny
22	20	06	Cloudy with rain becoming brighter w. a little sunshine
23	28	08	Bright & sunny, cloudy at times.
24	27	08	Warm humid day. Cloudy with sunny spells
25	CALM		Warm humid sunny day
26	11	06	Fog at first. Cloudy w. thunderstorms & heavy rain.
27	27	14	Cloudy, heavy rain & sunny intervals.
28	CALM		Cloudy, slight drizzle
29	05	04	Fog at first, cloudy, rain, heavy at night.
30	35	09	Rain, cloudy becoming bright w. sunny intervals.
31	CALM		Cloudy. Sunny intervals.
MEAN	6.16 knots.		
AVERAGE	6.1 Knots		

AUGUST 1985.

DAILY OBSERVATIONS AND WEATHER

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SNOW cm. Lying 0900 hours	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	14.5	11.6	17.6	10.2	7.3	15.2	13.8	3.0		2.6	1	4	01	6
2	15.1	14.1	18.5	10.3	9.2	15.0	13.7	0.1		7.5	1	8	52	6
3	14.0	13.4	16.9	10.4	7.8	15.0	13.7	-		7.9	1	5	01	6
4	14.5	14.1	16.5	8.9	4.5	14.7	13.9	24.3		6.4	0	5	02	7
5	13.0	11.0	16.9	9.9	9.0	14.5	13.8	2.7		6.4	2	6	02	6
6	14.9	12.3	17.9	9.6	6.9	14.5	13.8	5.0		6.1	1	5	02	7
7	13.1	12.3	16.1	8.8	6.2	14.6	13.8	0.3		0.3	1	8	03	6
8	13.8	13.1	17.0	7.7	3.3	14.3	13.8	3.0		7.3	0	4	02	7
9	14.5	13.1	18.2	9.6	5.6	14.3	13.8	-		7.1	1	5	02	7
10	14.5	13.6	18.3	6.5	3.1	14.3	13.1	tr		10.2	0	3	02	6
11	11.5	10.5	14.6	9.0	5.5	14.5	13.7	10.1		1.4	0	8	03	6
12	14.4	12.7	17.0	9.3	6.9	14.5	13.7	0.8		12.2	1	4	01	7
13	14.1	13.8	17.8	8.9	5.5	14.0	13.5	1.0		5.0	1	8	60	6
14	13.9	13.8	16.8	11.5	9.4	14.3	13.6	12.6		2.2	1	8	65	5
15	13.5	13.3	17.5	8.9	5.7	14.3	13.6	5.6		2.5	1	8	03	6
16	16.1	16.0	18.5	11.5	8.4	14.0	13.5	1.5		5.7	1	4	01	7
17	16.4	15.7	20.1	11.9	9.6	14.2	13.6	tr		7.9	1	4	01	7
18	12.6	12.2	18.6	10.6	10.1	15.0	13.6	0.8		0.4	1	8	03	4
19	16.2	15.1	19.5	12.5	11.3	15.0	13.6	2.1		3.6	1	5	01	6
20	13.5	13.4	17.3	12.6	8.3	15.0	13.6	0.3		2.9	1	8	03	6
21	15.1	14.9	18.4	12.6	10.2	14.6	13.9	-		4.4	1	6	02	7
22	12.9	12.7	16.7	11.5	8.3	14.6	13.9	-		3.6	0	8	03	6
23	12.3	12.1	16.2	10.6	7.0	14.1	13.9	3.9		1.0	0	8	02	6
24	14.9	14.7	16.5	11.7	9.8	14.0	13.7	0.2		8.2	1	4	02	7
25	13.3	13.2	16.0	8.7	5.7	13.8	13.7	1.1		2.7	0	7	03	7
26	13.5	11.2	17.4	10.0	8.2	13.7	13.6	0.7		5.9	1	5	03	7
27	14.0	12.9	20.7	7.5	4.5	13.7	13.5	-		2.8	1	7	03	7
28	16.3	13.4	18.6	13.0	10.5	14.3	13.5	-		6.3	0	4	03	7
29	13.0	11.5	15.1	10.1	7.6	14.4	13.5	1.1		0.0	0	8	02	6
30	15.1	14.1	20.5	11.3	10.0	14.3	13.5	0.1		6.9	1	6	01	5
31	12.5	11.6	17.5	11.6	9.4	14.5	13.5	1.2		4.7	1	8	62	6
MONTH	14.1	13.1	17.6	10.2	7.6	14.4	13.7	81.5		152.1		6.1		
AVERAGE			19.0	10.2				68.8		146.9				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
81.5 mm	118%	146.9 hrs	103.5	33

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	32	07	Cloudy, sunny intervals
2	23	10	Cloudy, rain, becoming brighter with sunny intervals.
3	25	12	Bright & sunny. Strong westerly wind.
4	23	16	Bright & sunny becoming cloudy, heavy rain at night
5	35	16	Bright & sunny with showers
6	32	11	Bright & sunny, becoming cloudy with thunderstorms
7	18	08	Cloudy, rain, becoming brighter in evening.
8	24	04	Bright & sunny, rain at night
9	23	08	Bright & sunny, rain at night
10	25	05	Bright & sunny
11	21	05	Bright at first, becoming cloudy with heavy rain, strong westerly winds.
12	26	14	Bright & sunny. S. westerly breeze. Heavy showers. Sunny periods.
13	19	09	Bright at first, becoming cloudy. Slight rain. S-SW wind.
14	17	03	Cloudy, rain, heavy at times, sunny intervals later.
15	18	11	Cloudy, strong S-S west winds, sunny intervals.
16	23	09	Bright & sunny. SW wind. Showers in afternoon & evening.
17	CALM		Bright & sunny, showers at night.
18	19	05	Cloudy, rain at night
19	26	02	Rain at first, becoming brighter, with sunny intervals.
20	20	06	Rain at first, becoming brighter with sunny intervals.
21	26	08	Cloudy, sunny intervals.
22	30	05	Bright at first, cloudy, some sunny intervals.
23	20	04	Cloudy, with sunny intervals and heavy showers
24	25	14	Bright, becoming cloudy, strong SW wind, sunny intervals with occasional showers.
25	25	16	Becoming cloudy after bright start.
26	30	07	Bright & sunny becoming cloudy with sunny intervals.
27	20	07	Cloudy, dry day w. fresh SW breeze. Sunny intervals.
28	24	07	Bright & sunny, cloudy at times, remaining dry.
29	10	02	Cloudy day with a few showers
30	19	03	Cloudy and misty becoming bright & sunny
31	18	08	Cloudy with rain becoming bright & sunny
MEAN	7.8 knots		
AVERAGE	5.4 Knots		

SEPTEMBER 1985

DAILY OBSERVATIONS AND WEATHER

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SNOW cm. Lying 0900 hours	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	13.8	11.5	17.9	11.1	9.0	14.0	13.5	0.1		3.8	1	6	62	7
2	12.2	10.9	14.4	10.0	6.9	14.0	13.5	4.4		0	1	8	03	6
3	14.3	13.0	15.0	9.7	7.5	13.5	13.6	5.4		2.3	2	7	01	6
4	10.1	9.1	12.6	6.0	2.7	13.4	13.5	2.8		0.1	1	8	02	5
5	12.5	10.1	15.1	9.7	7.8	13.4	13.5	tr		8.9	1	6	01	7
6	11.0	7.1	14.8	5.0	0.2	13.0	13.4	0.5		10.1	1	1	01	7
7	8.1	7.4	12.3	4.6	1.2	12.9	13.4	14.1		0	1	7	50	5
8	12.3	12.1	13.3	7.1	7.0	12.9	13.2	0.1		0	1	7	02	6
9	12.4	12.0	19.7	9.5	8.5	12.9	13.2	-		0.9	1	8	03	5
10	18.5	14.9	22.3	12.2	11.5	13.5	13.1	-		9.9	1	1	01	7
11	14.0	13.3	20.3	8.7	5.6	13.5	13.1	-		6.1	1	3	01	5
12	17.1	14.8	23.5	10.5	6.4	14.2	13.2	0.1		8.1	1	0	02	6
13	13.5	12.7	16.4	8.9	4.8	14.3	13.3	0.8		8.1	0	4	02	6
14	14.0	13.9	16.3	10.5	8.5	13.8	13.4	0.1		7.2	1	7	62	5
15	12.8	11.1	15.2	8.9	7.1	13.5	13.3	-		8.3	0	3	01	7
16	11.1	10.6	17.5	8.7	6.7	13.0	13.3	0.3		0.3	0	8	03	6
17	15.2	14.9	17.6	10.5	10.0	13.3	13.4	-		8.6	0	2	01	7
18	11.4	10.8	16.3	9.9	7.3	13.3	13.2	4.7		0	0	8	03	6
19	15.5	14.5	15.8	11.1	10.7	13.4	13.2	0.1		2.0	1	8	02	6
20	10.5	9.2	17.1	5.3	1.5	12.9	13.1	3.1		1.4	1	7	01	7
21	17.1	15.5	20.0	9.2	8.5	12.7	13.1	13.8		3.2	1	5	01	7
22	10.9	10.6	14.5	9.3	9.1	12.9	13.1	0.2		0	2	8	43	3
23	14.4	13.6	17.7	10.1	8.3	13.0	13.1	-		3.2	2	7	01	6
24	13.6	12.7	16.9	12.0	9.5	13.3	13.1	-		3.9	0	4	01	7
25	12.4	11.0	17.6	7.7	4.6	13.2	13.1	1.3		0.3	0	7	03	6
26	16.7	15.8	20.5	12.2	12.0	13.6	13.2	-		1.8	1	7	02	6
27	16.0	14.9	23.2	13.6	11.8	14.1	13.4	-		2.8	0	6	01	6
28	14.3	13.7	21.0	9.0	6.9	14.3	13.1	-		7.2	1	4	40	4
29	13.9	13.0	17.3	9.4	7.2	14.3	13.2	-		3.9	1	3	40	4
30	16.1	14.7	22.7	13.5	10.7	14.3	13.2	tr		3.5	1	7	02	5
MONTH	13.5	12.3	17.5	9.5	7.3	13.5	13.3	51.9		115.9		5.6		
AVERAGE			16.9	8.5				50.6		126				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
51.9 mm	102%	115.9 hrs	92%	30%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	29	14	Cloudy, becoming brighter with sunny intervals.
2	16	02	Cloudy, rain
3	21	02	Bright at first, becoming cloudy with heavy rain
4	CALM		Cloudy, rain
5	35	09	Bright & sunny. Dry day
6	35	09	Bright & sunny, rain at night
7	CALM		Cloudy, slight drizzle
8	07	04	Rain
9	21	02	Cloudy, becoming brighter late afternoon
10	22	07	Bright & sunny, warm dry day
11	24	02	Cloudy at first, becoming brighter, warm dry
12	21	06	Bright & sunny, warm dry day. Slight rain at night
13	27	09	Bright & sunny. Cool N-N.west wind.
14	24	12	Cloudy, becoming brighter with sunny intervals, rain at night.
15	29	20	Bright & sunny. Strong SW wind.
16	23	08	Cloudy, rain, becoming brighter by late afternoon.
17	30	13	Bright & sunny. Strong NW wind. Continuing sunny.
18	18	04	Cloudy, dull, rain
19	24	07	Cloudy, rain, clearing becoming brighter w. sunny intervals.
20	24	09	Cloudy, becoming brighter, sunny intervals.
21	25	20	Cloudy, becoming brighter, mild. Rain at night.
22	10	02	Rain. Dull damp day.
23	CALM		Cloudy, becoming bright w. sunny intervals. Warm dry day.
24	27	06	Bright & sunny intervals.
25	CALM		Cloudy
26	26	06	Rain at first, cloudy, mild becoming brighter, w. sunny intervals.
27	CALM		Cloudy, mild becoming brighter w. sunny intervals. Fog at night.
28	CALM		Fog at first, becoming bright warm dry day. Fog at night.
29	19	06	Fog at first becoming brighter w. sunny intervals.
30	21	02	Cloudy, warm with sunny intervals. Slight rain at night & fresh S-SW wind.
MEAN	6 knots.		
AVERAGE	6.8 Knots		

TABLE 1 DAILY OBSERVATIONS AND WEATHER

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SNOW cm. Lying 0900 hours	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	18.5	17.6	24.1	15.9	13.6	14.8	13.3	-		5.2	0	3	01	5
2	16.0	15.4	19.6	12.3	9.0	15.0	13.4	0.7		4.2	0	3	02	6
3	15.3	15.2	16.0	14.5	12.3	14.8	13.4	2.7		2.7	1	8	62	5
4	14.0	13.8	16.5	10.5	8.5	14.1	13.3	1.4		6.8	1	3	01	6
5	14.2	14.0	15.3	10.4	7.5	13.6	13.5	tr		6.9	1	3	01	6
6	12.3	11.5	15.1	8.9	4.2	13.1	13.5	10.7		0.4	1	7	03	6
7	11.0	9.7	14.0	7.6	3.1	12.7	13.5	0.3		5.2	2	4	01	6
8	10.1	9.7	12.5	5.7	2.0	12.3	13.2	0.3		5.4	1	5	02	6
9	11.0	9.9	13.7	6.9	2.8	11.9	13.0			2.6	1	7	03	6
10	12.0	11.7	16.9	8.5	5.5	11.6	12.9			4.5	1	4	01	7
11	12.4	12.3	15.6	10.7	8.2	12.2	13.1			7.1	0	4	02	7
12	8.9	7.7	14.6	2.5	-0.6	11.6	13.1			8.4	1	2	01	6
13	10.8	9.2	17.6	5.1	2.4	11.4	13.0			7.7	1	1	02	6
14	13.7	11.5	19.5	9.3	5.6	12.0	13.2			9.0	1	1	02	6
15	14.6	13.2	15.1	12.0	8.2	12.5	13.2			0.5	1	7	03	6
16	11.3	10.0	16.4	9.9	6.4	12.3	13.2			4.7	0	8	02	5
17	8.5	8.4	13.0	4.5	2.6	12.3	13.1			1.3	1	9	45	4
18	10.4	10.0	12.0	8.1	7.5	12.3	13.1			1.0	1	8	02	5
19	6.0	5.0	12.6	1.3	-1.6	11.5	12.9			7.3	1	2	01	6
20	8.0	7.8	13.0	5.8	4.6	10.6	12.5			0.8	1	9	45	4
21	9.0	8.0	14.4	5.9	1.8	11.4	12.3			3.8	1	3	01	5
22	11.3	10.2	11.7	8.4	5.7	11.4	12.3			0.6	0	4	02	6
23	10.2	8.6	11.6	6.3	2.2	11.2	12.2			0.5	0	5	02	5
24	9.8	9.1	12.5	8.7	7.5	11.1	12.1			4.6	0	9	43	4
25	10.1	9.5	12.6	4.0	-1.1	10.7	12.0			4.7	0	9	01	5
26	9.4	8.1	11.0	7.5	4.5	10.8	12.0			0.0	0	7	01	5
27	8.5	7.2	10.2	6.1	0.8	10.6	11.9			1.0	0	8	01	6
28	8.0	7.1	10.7	4.0	0.1	10.3	11.8	tr		0.4	0	6	01	6
29	9.0	8.5	11.3	7.7	3.5	10.1	11.6			0.3	0	8	03	6
30	3.4	2.8	9.9	-0.5	-3.5	10.0	11.5	3.4		1.8	1	4	01	6
31	6.6	6.4	8.1	3.1	-0.9	9.5	11.5	1.7		0.3	2	8	62	6
MONTH	10.8	10.0	14.1	7.5	4.3	11.9	12.7	21.2		109.7		5.3		
AVERAGE			13.2	5.8				64.3		91.8				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
21.2	32.9	109.7	120%	33.8%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	19	05	Cloudy at first, becoming brighter, warm dry day.
2	18	06	Bright & sunny, warm becoming cloudy, rain at night
3	20	12	Cloudy, rain, strong S to SW wind, becoming brighter w. sunny int.
4	20	14	Bright & sunny, strong S to SW winds, rain at night
5	23	10	Bright & sunny, warm day with rain at night
6	19	15	Rain, heavy at times
7	23	06	Bright & sunny, rain at night
8	25	07	Bright & sunny becoming cloudy by afternoon w. rain at night
9	30	10	Cloudy, fresh N-NW wind, sunny intervals
10	23	08	Cloudy, becoming brighter w. sunny intervals
11	31	15	Bright & sunny, warm dry day
12	CALM		Slight ground frost, bright & sunny dry day
13	CALM		Bright & sunny dry day
14	31	02	Bright & sunny, warm dry day
15	28	01	Cloudy, dry day
16	23	02	Cloudy, becoming brighter w. sunny intervals, fog at night
17	CALM		Fog, clearing by the afternoon, to give a little sunshine
18	35	05	Cloudy, becoming brighter in the afternoon. Sunny intervals
19	28	02	Ground frost, bright & sunny
20	10	01	Fog, cloudy
21	CALM		Bright & sunny
22	11	05	Cloudy at first, becoming brighter
23	12	04	Cloudy, a little sunshine late afternoon. Fog at night
24	19	03	Fog; cloudy becoming brighter with sunny intervals
25	06	06	Fog at first, becoming brighter
26	02	02	Cloudy, calm day
27	CALM		Cloudy, becoming brighter late afternoon, sunny intervals
28	33	04	Cloudy, sunny intervals
29	04	02	Cloudy, becoming brighter
30	23	03	Frost, bright & sunny, becoming cloudy
31	05	03	Slight ground frost, rain.

MEAN 4.94 knots

AVERAGE 6.9 Knots

NOVEMBER

DAILY OBSERVATIONS AND WEATHER

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SNOW cm. Lying 0900 hours	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	5.8	4.6	8.9	1.2	-3.0	9.0	11.3	1.0		4.8	1	2	01	6
2	2.3	0.6	5.6	-1.1	-4.6	8.4	11.3	-		8.1	1	1	02	7
3	0.9	-0.5	6.4	-3.4	-6.9	7.4	11.1	-		2.7	1	6	03	6
4	3.1	2.0	7.9	-0.5	-3.6	6.9	9.8	7.6		4.1	1	3	01	5
5	5.8	5.4	8.5	3.7	2.9	7.1	10.5	0.9		2.3	2	7	03	6
6	3.9	1.8	9.1	0.1	-2.4	6.9	10.3	0.1		2.8	1	4	01	6
7	7.7	6.0	10.0	3.6	2.5	6.9	10.3	4.2		5.9	1	3	02	6
8	8.1	8.0	12.9	2.5	-0.5	6.9	10.0	2.2		0.0	2	9	43	4
9	9.3	7.5	10.6	7.1	4.1	7.6	9.9	14.6		1.9	1	4	01	7
10	0.8	-1.1	3.9	-1.1	-3.3	7.4	9.8	-		8.1	2	1	01	7
11	2.4	0.4	4.5	-0.6	-3.2	6.1	9.6	-		6.6	4	1	02	7
12	0.4	-0.1	5.2	-1.0	-2.2	5.4	9.5	0.1		3.7	4	2	02	6
13	2.0	0.3	7.7	0.1	-2.0	5.2	9.3	-		6.2	1	4	02	6
14	0.5	0.1	3.5	-3.5	-5.6	4.9	9.1	2.2		0.0	4	9	45	3
15	3.0	2.9	4.6	0.3	-0.7	5.4	8.9	1.8		0.0	2	9	45	3
16	2.6	2.2	5.1	0.9	-1.6	5.2	8.7	6.5		0.0	2	8	62	4
17	2.4	1.6	8.1	0.0	-3.2	5.6	8.5	0.1		5.2	2	3	01	6
18	2.8	2.8	5.1	-0.4	-3.3	5.6	8.4	0.6		0.2	2	9	45	0
19	2.9	2.3	4.0	1.5	-2.4	5.6	8.3	1.2		0.4	2	8	62	6
20	3.6	2.7	4.9	1.9	-0.3	5.6	8.3	1.0		0.0	2	7	01	6
21	3.5	2.8	5.6	2.3	0.9	5.7	8.0	1.8		1.5	2	8	62	5
22	3.5	2.6	5.1	1.9	0.1	4.7	7.9	3.4		0.5	1	8	50	6
23	5.1	4.7	5.3	2.9	1.8	5.0	7.8	3.4		0.0	2	6	02	6
24	4.2	3.9	6.5	1.9	-1.9	5.1	7.7	2.2		2.7	2	5	01	5
25	3.5	3.0	6.1	2.3	-0.2	5.0	7.6	1.6		2.4	2	4	01	6
26	2.0	1.1	4.0	0.6	-1.6	5.0	7.6	tr		3.3	2	4	02	6
27	0.2	-1.4	2.9	-2.5	-6.4	4.3	7.5	2.2		5.9	4	1	01	6
28	-3.0	-3.0	3.0	-4.0	-6.7	3.5	7.4	1.2	3	4.6	7	2	02	6
29	-3.1	-3.2	3.5	-4.2	-8.2	3.4	7.3		3	3.9	7	4	02	5
30	0.5	-0.1	12.4	-5.9	-8.1	3.0	7.2	8.2	3	0.0	7	5	02	5
MONTH	2.9	2.0	6.4	0.2	-2.3	5.8	(9.0)	68.1		87.8		4.9		
AVERAGE			8.9	3.0				56.9		58.8				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
68.1 mm	120%	87.8 hrs	149%	34%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	29	04	Groundfrost, bright & sunny, rain
2	32	12	Frost, bright & sunny, rain at night
3	20	02	Frost, bright & sunny becoming cloudy cold day
4	26	02	Frost bright & sunny cold day
5	32	10	Rain at first, cloudy showers & sunny intervals. W winds
6	27	05	Bright & sunny, ground frost, rain
7	31	12	Bright & sunny, N W Wind
8	17	04	Ground frost, cloudy rain at first
9	24	12	Bright & sunny, rain at night
10	32	18	Frost bright & sunny cold day
11	31	10	Bright & sunny frost, cold day
12	34	09	Frost, cold, bright & sunny. Slight shower
13	33	05	Ground frost, bright & sunny
14	19	04	Frost fog. Dull damp day
15	CALM		Fog ground frost dull
16	21	06	Rain, groundfrost
17	31	03	Bright & sunny, ground frost
18	CALM		Fog, frost, clearing to give a little sunshine. Then cloudy
19	09	02	Rain, ground frost, becoming brighter
20	06	05	Cloudy, rain
21	07	05	Rain, becoming bright with sunny intervals
22	01	06	Cloudy, slight drizzle
23	06	08	Cloudy, rain
24	03	02	Cloudy, ground frost, sunny intervals, rain at night
25	01	03	Cloudy, slightly ground frost, rain becoming brighter, w. sunny intervals
26	32	07	Ground frost, bright & sunny
27	CALM		Frost, bright & sunny
28	31	01	Snow, bright & sunny, snow showers at night
29	CALM		Frost, bright & sunny, snow covering the ground completely
30	CALM		Frost, cold dull day snow covering the ground
MEAN	= 5.23 Knots		
AVERAGE	8.0 Knots		

DECEMBER

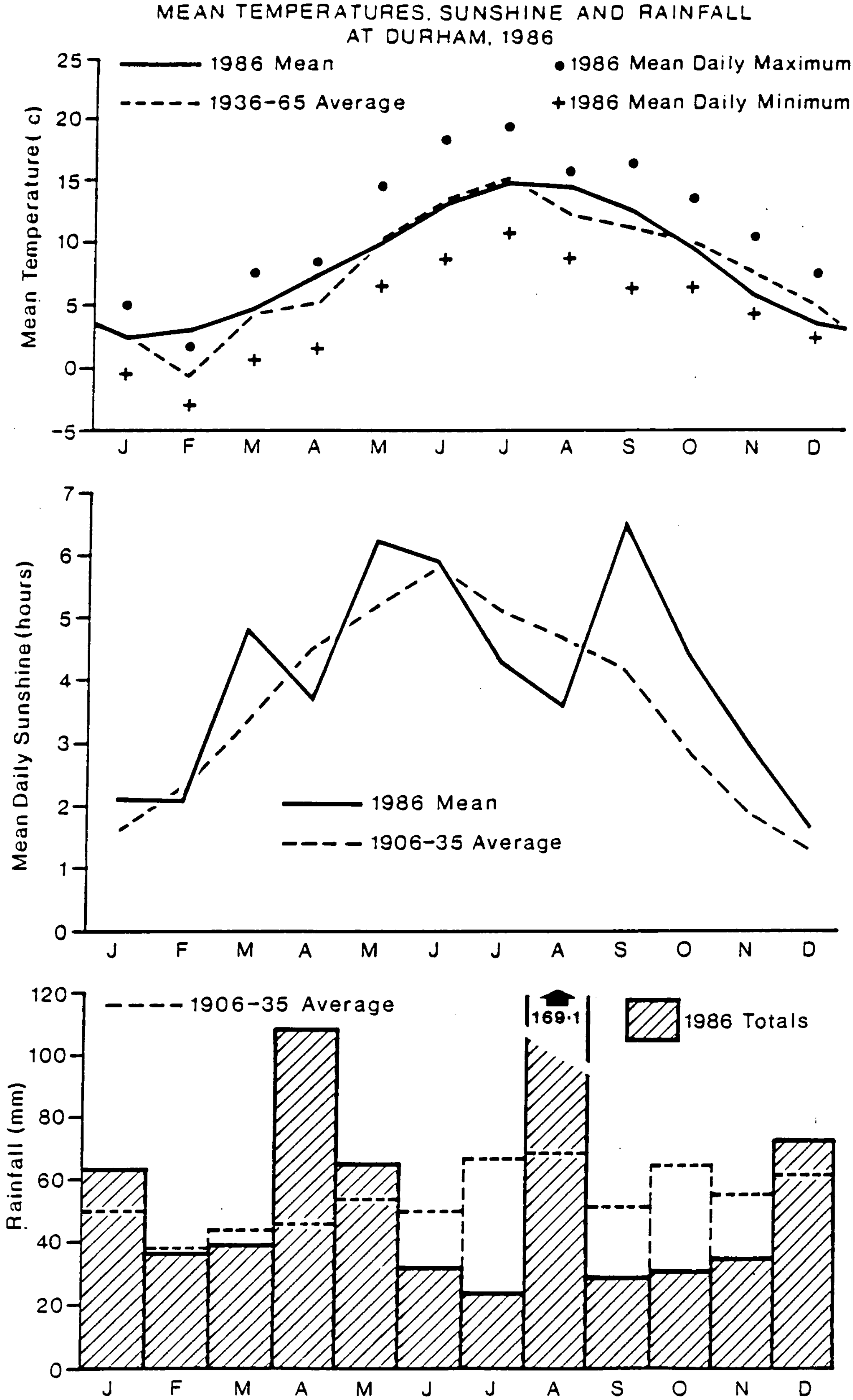
DAILY OBSERVATIONS AND WEATHER

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SNOW cm. Lying 0900 hours	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	11.9	11.5	14.5	-0.1	-0.9	3.2	7.1	0.1		0	2	6	03	5
2	9.6	9.6	14.3	8.5	7.0	5.0	6.8	1.6		0	1	7	02	6
3	11.9	9.1	12.5	8.7	7.5	6.1	6.8	-		4.5	1	3	01	6
4	9.0	8.6	9.4	8.2	4.5	6.4	6.8	3.5		0	1	8	03	6
5	6.5	6.3	6.6	4.2	2.4	6.2	7.1	2.6		0	2	9	45	3
6	3.4	2.8	6.4	2.7	0.2	5.8	7.1	2.8		0.8	2	5	01	6
7	5.1	4.2	4.9	3.2	1.0	5.5	7.2	3.0		0.1	2	3	01	7
8	0.3	0.2	1.8	-0.2	-0.9	5.4	7.2	0.1		0	2	9	45	0
9	0.1	-0.4	5.0	-2.5	-5.5	4.5	7.0	tr		4.5	4	6	01	5
10	-2.4	-2.5	1.9	-3.2	-6.2	3.8	7.0	3.2		0	4	3	01	4
11	1.0	1.0	8.3	-2.7	-4.3	3.4	6.9	0.2		3.7	4	6	46	1
12	7.6	7.1	11.2	-0.1	-1.5	3.6	6.7	tr		0	2	5	02	5
13	7.5	6.6	10.2	7.1	4.1	4.7	6.6	-		0	1	7	02	6
14	10.0	9.1	12.1	5.7	2.1	5.2	6.6	-		0	1	7	02	6
15	12.1	9.8	12.3	9.1	7.2	5.9	6.5	-		0	1	5	02	6
16	11.0	8.3	11.3	9.5	7.4	6.4	6.8	0.3		0	1	6	02	6
17	9.6	9.1	11.0	8.9	6.0	6.7	6.9	7.1		0	2	8	03	5
18	6.3	5.1	9.0	6.0	3.1	6.9	6.9	0.3		5.6	2	1	01	6
19	5.3	3.9	9.3	4.0	1.0	6.9	6.9	3.1		1.3	1	4	02	6
20	7.0	5.2	12.0	4.8	1.5	6.8	7.1	2.2		0	1	8	03	6
21	11.9	10.2	12.9	5.4	4.4	6.5	7.1	0.8		0.8	2	6	02	7
22	4.6	4.0	6.6	4.0	1.5	6.7	7.1	0.1		0.6	2	5	02	6
23	5.9	5.0	7.5	2.8	-0.4	5.7	7.2	0.5		0.3	2	4	62	6
24	0.6	0.5	7.1	0.1	-2.8	5.3	7.2	6.5		4.0	2	1	01	5
25	5.1	5.0	5.5	-1.4	-3.2	4.6	7.0	1.8		0	2	7	62	5
26	3.1	1.4	3.2	1.4	-0.6	4.7	6.9	tr		0	1	7	02	6
27	-2.6	-3.0	-1.8	-3.8	-6.4	4.0	6.8	tr		6.4	4	2	02	7
28	-4.2	-4.4	-1.0	-5.0	-7.1	3.3	6.8	-		6.1	4	1	02	7
29	-3.1	-3.4	-0.4	-5.6	-8.5	2.8	6.6	-		3.2	4	3	02	7
30	-3.1	-3.3	3.4	-6.2	-8.9	2.4	5.4	0.4		0	4	6	03	6
31	3.2	2.7	3.9	-3.5	-4.6	2.1	6.2	0.3		0	4	7	62	5
MONTH	5.0	4.2	7.4	2.3	-0.03	5.0	6.8	40.5		41.9		5.3		
AVERAGE			6.4	1.0				61.5		41.85				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
40.5 mm	66%	41.9 hrs	100%	18.6%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	21	12	Cloudy, groundfrost rain becoming mild
2	CALM		Cloudy, mild, rain
3	25	22	Cloudy, mild w. a strong SW wind
4	17	02	Cloudy, rain, fog at night
5	19	03	Fog, rain, dull damp day
6	21	01	Bright, rain
7	28	11	Cloudy, cold, rain at night
8	22	12	Fog, frost, cold day, fog at night, frost
9	31	02	Cloudy, frost, becoming higner w. sunny intervals
10	20	03	Frost, bright & sunny at first, fog, rain by late afternoon
11	CALM		Bright at first, fog & frost, becoming mild
12	22	08	Cloudy, groundfrost
13	05	01	Cloudy, mild
14	23	06	Cloudy, continuing mild
15	25	06	Cloudy, mild
16	27	10	Cloudy, mild
17	22	04	Rain
18	31	12	Bright & sunny, rain at night
19	27	07	Cloudy becoming brighter w. sunny intervals, rain at night
20	25	07	Cloudy, rain
21	23	24	Cloudy, rain, sunny intervals, rain at night
22	13	02	Cloudy becoming brighter, rain at night
23	24	08	Cloudy, ground frost, becoming brignter
24	20	02	Ground frost becoming brighter w. sunny intervals, rain at night
25	CALM		Cloudy, rain, frost, rain at night
26	05	16	Cloudy
27	31	10	Frost, bright & sunny, cold dry day
28	31	10	Frost, bright & sunny, cold dry day
29	33	12	Frost, bright & sunny
30	20	06	Frost, cold day
31	20	10	Frost, cloudy, becoming mild
MEAN = 7.39 Knots			
AVERAGE 9.1 Knots			

Daily Meteorological Observations 1986


MEAN TEMPERATURES, SUNSHINE AND RAINFALL
AT DURHAM, 1986
1986 Mean
1936-65 Average
1986 Mean Daily Maximum
+1986 Mean Daily Minimum
Mean Temperature(c)
25
20
15
10
5
0
-5
J F M A M J J A S O N D
Mean Daily Sunshine (hours)
7
6
5
4
3
2
1
0
1986 Mean
1906-35 Average
J F M A M J J A S O N D
Rainfall (mm)
120
100
80
60
40
20
0
1906-35 Average
169·1
1986 Totals
J F M A M J J A S O N D

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SNOW cm. Lying 0900 hours	SUN-SHINE hours	State of ground without snow / with snow	Cloud	Present weather	Visibility
1	2.5	2.0	4.5	0.7	-2.0	2.0	6.0	11.1		0.9	4	6	02	6
2	2.7	2.4	3.3	1.0	-1.1	1.6	5.9	5.3		0.0	2	8	63	5
3	0.3	-0.4	1.6	-0.6	-3.5	1.8	5.6	tr		4.9	1	6	70	5
4	-2.5	-3.0	0.1	-4.4	-10.2	1.8	5.5	4.0	1	1.5	3	4	01	7
5	-4.7	-5.1	2.1	-6.4	-7.0	1.8	5.8	2.8	3	0.1	7	2	01	5
6	-0.3	-1.0	0.3	-5.3	-8.3	1.7	5.7	0.9	3	0.0	7	5	03	5
7	-0.4	-0.9	1.8	-3.9	-3.3	1.7	5.3		4	0.0	7	7	02	5
8	1.8	0.6	1.7	-0.9	-1.9	1.7	5.2	0.2	3	0.0	7	7	02	5
9	0.9	0.4	7.9	0.2	-1.1	1.6	5.2	1.6	3	0.0	7	8	70	5
10	7.9	7.2	7.9	0.1	-0.9	1.5	4.9	0.5		2.5	2	7	62	5
11	4.9	2.7	5.6	2.5	-0.6	2.9	4.8	tr		5.1	2	2	01	6
12	5.3	3.6	9.0	3.6	-1.2	2.4	4.8			4.6	1	2	02	7
13	8.9	7.0	9.9	4.5	3.0	4.0	4.6	1.0		0.0	1	7	03	6
14	4.5	2.4	7.0	1.9	0.7	3.5	4.8	0.3		5.0	1	2	01	6
15	4.0	3.9	5.0	1.7	1.0	3.4	4.8	0.3		1.7	2	8	63	6
16	0.5	-0.7	3.5	0.1	-2.6	3.0	4.8			2.1	4	7	01	6
17	-2.0	-2.4	8.8	-3.2	-6.1	2.5	4.9	1.0		0.0	4	3	01	6
18	8.5	7.1	9.5	-2.4	-4.1	2.4	4.9	2.4		0.0	1	5	03	6
19	9.5	8.2	9.9	4.9	1.2	3.1	4.9	6.3		0.1	1	5	02	7
20	4.6	3.7	8.5	2.1	-0.1	3.2	4.7	3.0		0.3	2	4	02	6
21	4.8	3.4	6.5	3.4	0.1	3.6	4.8	0.3		2.7	2	1	01	7
22	2.8	2.5	7.8	0.8	-2.4	3.6	4.8	2.8		0.9	2	8	63	5
23	3.2	2.0	4.9	2.0	-0.5	3.0	4.9	0.1		6.0	1	2	01	7
24	1.0	0.1	3.2	-0.3	-2.5	2.7	4.8			6.7	4	2	02	7
25	-0.6	-0.8	3.6	-2.1	-4.5	2.3	4.9			7.5	4	1	02	6
26	-3.9	-4.2	2.2	-6.4	-8.7	1.8	4.8	tr		7.3	4	1	02	6
27	0.6	0.6	3.0	-4.1	-4.5	1.8	4.6	1.3		0.0	4	8	50	3
28	0.1	-0.3	3.3	-1.7	-5.5	1.6	4.5	6.4		3.9	4	4	01	6
29	0.5	0.4	3.5	-0.4	-2.2	1.5	4.4	7.4		0.0	7	8	68	4
30	3.1	2.5	4.6	0.1	-1.2	1.5	4.4	1.3		0.0	1	8	62	5
31	2.7	2.4	3.4	2.0	0.6	1.5	4.4	2.8		0.0	2	8	63	5
MONTH	2.3	1.5	5.0	-0.3	2.6	2.3	5.0	63.1		63.8		5		
AVERAGE			5.3	-0.1				49.3		50.2				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
63.1mm	128%	63.8 hrs	127%	26%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	CALM		Cloudy, ground frost, becoming brighter with sunny intervals, rain at night
2	09	10	Rain, ground frost
3	34	07	Snow showers
4	CALM		Frost, bright and sunny, snow at night
5	CALM		Frost, bright and sunny, cold dry, snow showers
6	33	07	Frost, snow showers, cold day
7	18	04	Frost, cloudy
8	13	07	Cloudy, frost
9	21	09	Cloudy, ground frost, slight snow showers
10	24	20	Cloudy, slight ground frost becoming milder, rain w. sunny inter-
11	25	18	Ground frost, strong W winds, becoming brighter, sunny int. vals
12	28	22	Bright w. sunny intervals, ground frost. Strong winds
13	28	08	Cloudy, wind moderating, rain, strong west winds at night
14	28	22	Cloudy, becoming brighter, strong west winds cont. sunny intervals
15	34	10	Rain at first, clearing to give sunny intervals, rain at night
16	31	04	Frost, cloudy at first becoming brighter with sunny intervals
17	CALM		Frost, becoming brighter
18	29	20	Cloudy, ground frost, rain
19	25	20	Cloudy, rain
20	22	07	Cloudy, ground frost, rain at night
21	26	09	Bright and sunny
22	21	10	Ground frost, rain becoming brighter late afternoon. Rain at night
23	27	20	Bright and sunny. Strong west winds. Ground frost, slight snow showers
24	33	15	Frost, bright and sunny, strong west winds
25	32	08	Frost, bright and sunny
26	22	02	Frost, bright and sunny
27	21	03	Cloudy, frost, slight drizzle, sleet & snow showers
28	21	03	Frost, bright and sunny
29	CALM		Snow showers
30	09	11	Rain
31	08	08	Rain, NE wind
MEAN	9.16 knots		
AVERAGE	10.1 mph (9.6 knots)		

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SNOW cm. Lying 0900 hours	fresh fall	SUN-SHINE hours	State of ground without snow	with snow	Cloud	Present weather	Visibility
1	2.4	1.7	2.5	1.2	0.0	1.5	4.4	3.2			0.0	2		7	02	5
2	2.5	2.2	2.7	1.5	0.1	1.7	4.2	7.2			0.0	2		7	62	5
3	2.0	1.7	2.6	0.7	0.0	2.0	4.0	2.2			0.0	2		7	62	5
4	2.6	1.3	3.1	1.0	0.4	2.0	4.0	0.4			0.1	2		8	03	5
5	2.5	1.1	2.0	-0.4	-4.0	2.0	4.0	6.0			1.3	4		6	01	6
6	-0.7	-0.5	0.7	-2.4	-5.3	1.6	4.1	1.1	5	5	0.8		7	8	72	5
7	0.7	0.5	2.4	-1.2	-2.5	1.7	4.0	0.6	5		3.9		7	7	01	6
8	0.7	0.4	1.8	-0.9	-2.2	1.7	4.1	0.7	5		0.1		7	6	02	6
9	-0.1	-0.6	0.9	-1.0	-1.5	1.7	4.0		4		0.0		7	6	02	6
10	-5.0	-5.2	-3.5	-6.1	-7.6	1.6	4.0		4		0.0		7	9	45	1
11	-10.5	-10.5	-0.5	-11.8	-12.0	1.4	3.9		3		0.0		7	5	01	4
12	-0.5	-0.5	0.0	-9.5	-9.8	1.4	3.9		3		0.0		7	8	03	5
13	-1.3	-1.4	3.5	-7.3	-9.1	1.3	3.9	tr	3		5.8		7	3	01	5
14	-0.2	-0.3	0.9	-1.6	-4.5	1.3	3.9	0.5	2		0.0		7	8	03	5
15	0.3	0.1	1.9	-0.9	-2.3	1.3	3.9		2		0.0		7	8	02	5
16	1.9	0.5	1.9	-0.2	-1.1	1.2	3.7		2		0.0		7	8	02	5
17	1.4	0.5	1.9	0.1	-1.3	1.2	3.7	tr	2		0.2		7	8	02	5
18	1.8	0.6	2.4	-0.2	-3.6	1.2	3.5	1.6	2		0.0	2		7	02	6
19	-0.5	-0.8	2.6	-1.4	-2.5	1.2	3.5	4.4	2	1	2.6		7	8	70	5
20	-3.5	-3.7	1.0	-4.0	-4.6	1.2	3.5	0.5	9	8	6.8		7	6	01	5
21	-3.7	-3.9	1.2	-9.5	-9.7	1.2	3.5	2.0	8		0.7		7	8	70	5
22	-3.3	-3.6	0.6	-6.6	-5.5	1.2	3.7	0.7	10	2	6.3		7	1	01	6
23	-2.8	-3.2	2.9	-5.4	-4.2	1.2	3.6		10		6.7		7	2	02	5
24	-0.7	-1.1	3.5	-7.6	-7.8	1.2	3.6	6.0	8		3.7		7	3	02	5
25	-0.5	-0.7	2.5	-1.3	-3.2	1.1	3.5	tr	15	7	3.0		7	8	73	5
26	-2.0	-2.2	1.2	-5.1	-7.1	1.1	3.5	0.1	10		6.5		7	8	70	5
27	0.6	0.5	3.0	-2.8	-7.5	1.1	3.4	0.4	6		2.6		7	7	01	6
28	1.4	0.6	3.5	-0.4	-2.5	1.1	3.4	tr	6		5.7		7	4	01	6
MONTH	-0.5	-0.9	1.8	-3.0	-4.3	1.4	3.8	37.6			56.8			6.5		
AVERAGE			6.0	0.1				38.1			64.1					

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
37.6	98.7%	56.8	88%	21%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	07	14	Cloudy, strong NE wind, rain
2	06	16	Cloudy, rain & sleet showers, strong NE wind continuing
3	06	08	Rain and sleet showers
4	10	08	Cloudy, rain
5	34	08	Cloudy, snow showers & sunny intervals. Cold day
6	08	07	Snow covering ground completely, intermittent snow showers & sunny intervals
7	10	07	Bright and sunny: frost, snow covering ground
8	05	02	Cloudy, frost, snow showers
9	33	05	Cloudy, frost, snow showers
10	24	04	Cloudy, frost, fog, cold day
11	24	01	Frost, cloudy at first, becoming brighter, cold day
12	17	05	Cloudy, frost, cold day
13	C A L	M	Cloudy at first, becoming brighter, frost, sunny periods
14	11	08	Cloudy, frost
15	15	09	Cloudy, frost
16	09	06	Cloudy, frost
17	10	10	Cloudy, ground frost
18	05	05	Cloudy, frost
19	34	01	Cloudy, snow showers, sunny intervals, snow at night
20	32	01	Cloudy at first becoming brighter, snow covering the ground completely, sunny intervals. Slight snow showers at night
21	25	01	Cloudy, frost, slight snow showers, sunny intervals
22	32	06	Frost, bright & sunny with snow showers
23	C A L	M	Frost, bright & sunny with snow showers
24	34	03	Frost, bright and sunny
25	18	02	Frost, snow showers, becoming brighter with sunny intervals
26	13	04	Bright, slight snow showers, frost
27	07	03	Bright, frost, slight snow showers with sunny intervals
28	09	05	Bright at first, becoming cloudy. Frost
MEAN	5.3 knots		
AVERAGE	8.4 knots		

DATE	TEMPERATURE °C							RAIN-FALL mm.	SNOW cm. Lying 0900 hours	SUN-SHINE hours	State of ground		Cloud	Present weather	Visibility
	Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass				Without snow	With snow			
1	1.2	0.7	3.1	-1.6	-4.0	1.2	3.5		6 fresh fall	9.3		7	3	02	6
2	0.8	0.6	3.7	-2.5	-5.9	1.1	3.5		5	4.8		2	6	03	6
3	-6.0	-6.7	6.1	-9.5	-10.9	1.1	3.4		3	2.0		2	7	02	6
4	5.9	5.0	10.0	-6.2	-6.6	1.0	3.3			0.0		1	7	02	6
5	7.0	5.4	8.0	5.3	3.0	1.5	3.5			9.6	2		1	01	7
6	5.2	3.5	8.4	2.9	0.1	2.3	3.4			7.5	2		1	02	7
7	5.4	4.1	9.2	2.1	-2.1	2.5	3.4			0.7	2		6	03	6
8	3.2	2.2	9.5	-0.6	-3.6	2.7	3.6	0.8		9.4	1		2	01	5
9	2.1	1.7	4.7	1.5	0.0	3.1	3.6	tr		0.0	1		8	60	5
10	4.3	4.0	9.3	0.8	-1.4	3.0	3.6			1.0	1		4	01	5
11	3.1	2.5	5.6	-1.5	-4.5	3.2	3.7	tr		2.2	1		3	01	5
12	1.6	1.6	4.6	1.2	0.9	3.2	3.7			0.0	1		9	45	1
13	0.5	0.1	4.1	-0.1	-0.5	3.4	3.7			0.0	1		8	03	5
14	4.0	3.2	8.1	0.1	-1.2	3.0	3.5			0.0	1		8	02	5
15	8.0	7.5	10.1	3.4	3.3	3.7	4.0			0.5	1		7	02	5
16	6.9	5.5	7.1	4.9	4.0	4.5	4.0	1.3		0.0	1		8	44	4
17	5.4	3.6	10.0	1.5	-1.7	4.4	4.2	tr		9.6	1		2	01	7
18	2.2	2.0	6.6	1.1	-1.5	4.5	4.1	2.4		0.0	1		9	47	3
19	5.5	3.5	11.6	1.8	-0.3	4.5	4.2	1.4		9.6	2		2	01	7
20	7.0	5.5	8.5	2.5	-1.9	4.5	4.2	1.1		6.4	2		3	60	7
21	7.1	5.3	9.5	0.5	-0.7	4.7	4.4	tr		2.0	1		3	01	7
22	9.2	7.6	11.8	5.3	4.3	5.0	4.4	2.9		0.6	1		5	03	7
23	5.1	3.1	7.0	1.8	-0.5	5.4	4.8	9.6		8.5	1		2	02	7
24	0.2	0.2	5.1	-0.1	-1.1	4.9	4.7	9.2	10 10	0.0		7	8	75	2
25	5.0	3.5	8.8	-0.2	-1.5	4.0	4.5	0.1	7	10.2		7	2	01	7
26	5.5	3.4	8.6	1.5	-3.5	3.5	4.2	3.1		8.3		1	2	02	7
27	6.5	4.6	8.9	3.8	2.4	4.2	4.7	tr		9.4	1		2	02	7
28	6.5	4.2	9.7	2.1	-1.9	4.5	4.9	1.6		6.8	1		3	02	7
29	7.4	4.9	10.0	3.6	1.3	4.8	4.9	1.0		6.6	1		2	02	7
30	4.5	2.1	8.5	10.2	-3.2	4.8	4.9	1.5		9.3	1		3	02	7
31	1.2	1.0	6.1	-0.3	-4.0	4.8	4.9	2.8		1.4		1	8	68	4
MONTH	4.2	3.1	7.8	0.8	-1.4	3.5	4.0	38.8		135.7			4.6		
AVERAGE			8.6	1.3				44.9		106					

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
38.8	86%	135.7	128%	37%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	06	12	Frost, bright and sunny. Cold NE wind
2	03	01	Frost, cloudy becoming brighter with sunny intervals
3	23	04	Frost, bright at first
4	24	14	Cloudy. SW wind becoming mild
5	24	15	Bright and sunny. Strong SW wind
6	26	14	Bright and sunny, SW wind
7	23	05	Cloudy, frost
8	20	01	Bright and sunny, frost
9	22	06	Cloudy, dull, damp day
10	21	01	Bright and sunny, ground frost, becoming cloudy
11	20	03	Bright and sunny, frost, becoming cloudy, cold damp day, fog at night
12	20	07	Fog, cold damp day
13	18	04	Cloudy, frost. Cold damp day
14	19	10	Ground frost. Cloudy
15	19	11	Cloudy, sunny intervals
16	20	11	Fog, dull damp day with rain at night
17	23	04	Bright and sunny, ground frost
18	22	08	Fog, ground frost, cloudy day with rain at night
19	32	08	Bright and sunny, slight ground frost , rain at night
20	26	24	Showers, ground frost, bright and sunny , strong W wind, rain
21	27	11	Ground frost , bright and sunny
22	22	16	Cloudy with sunny intervals
23	29	20	Ground frost, bright and sunny
24	05	04	Continuous snow covering the ground completely
25	31	08	Bright and sunny, frost
26	29	10	Bright and sunny, ground frost, rain at night
27	25	24	Bright and sunny, strong W wind
28	23	10	Bright and sunny, rain showers
29	30	14	Bright and sunny, rain showers
30	22	05	Frost, bright and sunny
31	CALM		Frost. Cloudy. Sleet & snow showers becoming brighter with some late afternoon sunshine
MEAN	9.2 knots		
AVERAGE	7.3 knots		

DAILY OBSERVATIONS AND WEATHER APRIL 1986

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	6.1	4.0	10.4	-0.8	-4.7	4.5	4.9	-	10.1	1	2	02	7
2	6.6	4.7	8.5	-0.9	-4.5	4.8	5.1	-	4.5	1	4	02	6
3	2.9	2.3	7.5	-2.1	-5.9	4.6	5.1	0.4	1.6	1	8	03	6
4	5.0	3.3	9.3	0.9	-1.8	4.6	5.1	1.1	7.2	1	6	01	6
5	5.2	3.6	7.9	1.0	-1.2	5.0	5.2	3.3	7.5	1	5	02	6
6	3.3	2.1	5.4	0.1	-1.1	5.1	5.2	3.2	7.3	1	7	69	6
7	2.7	2.0	3.6	-1.0	-4.1	5.0	5.2	18.5	0.0	1	8	69	6
8	1.8	1.5	5.5	0.1	-0.5	4.4	5.3	4.1	0.0	2	8	69	5
9	5.4	4.0	6.7	1.3	-0.4	4.4	5.3	0.2	1.5	2	8	03	6
10	2.4	0.4	4.2	1.5	0.1	4.4	5.3	0.2	1.0	1	8	08	6
11	4.0	2.0	9.5	-0.1	-2.5	4.3	5.2	3.3	0.7	1	7	01	6
12	5.2	4.2	8.2	2.7	1.9	5.1	5.2	tr	6.4	2	7	02	6
13	6.4	4.7	6.9	1.7	0.1	5.1	5.2	3.0	0.2	1	7	02	6
14	4.6	4.2	5.0	1.8	0.2	5.5	5.2	7.4	0.0	2	8	51	5
15	4.0	3.8	4.6	2.5	1.5	5.4	5.2	22.0	0.0	2	8	65	5
16	4.3	4.1	6.0	3.0	0.5	5.0	5.1	12.4	0.0	2	8	02	5
17	4.5	4.5	4.9	3.8	3.0	5.3	5.2	14.3	0.0	2	8	65	2
18	3.4	2.9	6.5	1.8	0.7	5.0	5.3	0.2	0.0	2	7	01	6
19	6.5	4.6	8.5	0.5	-2.5	5.2	5.6	4.9	5.6	2	4	01	6
20	7.2	7.0	10.6	4.1	3.0	5.9	5.6	1.5	5.5	2	7	62	5
21	7.5	6.1	8.6	1.8	-1.3	6.0	5.6	3.9	5.2	2	6	01	5
22	7.4	5.1	11.0	2.1	0.8	6.1	5.6	0.1	10.9	2	3	01	7
23	8.2	6.3	11.5	0.7	-3.3	6.3	5.7	3.1	7.2	1	3	02	7
24	7.7	7.3	9.4	4.0	0.4	6.8	5.8	1.5	0.0	2	8	42	3
25	6.8	6.5	12.0	5.4	4.8	7.1	5.9	0.1	4.6	2	9	43	4
26	10.4	7.7	13.5	2.4	-0.8	7.5	6.1	-	5.9	1	6	01	6
27	10.3	8.2	12.6	3.2	0.1	8.0	6.2	0.5	2.3	1	6	02	5
28	6.6	5.5	10.0	2.8	-1.1	7.8	6.1	0.3	1.6	2	8	63	6
29	9.0	5.7	11.2	2.2	-2.5	7.4	6.5	-	11.0	1	4	01	7
30	8.5	6.3	12.6	4.5	1.2	7.4	6.5	-	2.4	1	7	03	6
MONTH	5.8	4.5	8.4	1.7	-0.6	5.6	5.5	109.5	110.2		6.5		
AVERAGE			11.4	3.3				45.9	134.1				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
109.5	238%	110.2 hrs	82%	26%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	31	05	Bright and sunny. Frost
2	CALM		Frost, bright and sunny becoming cloudy
3	01	03	Frost, cloudy, sleet showers, becoming brighter w. sunny intervals
4	35	09	Ground frost, bright and sunny, rain at night
5	04	06	Bright and sunny, ground frost, sleet & snow showers at night
6	06	06	Bright and sunny, ground frost, sleet & snow showers at night
7	07	10	Sleet and snow showers, frost
8	05	12	Sleet and snow showers clearing by late afternoon
9	06	07	Bright at first, becoming cloudy, sleet showers
10	03	15	Cloudy, strong NE wind, sleet showers, sunny intervals
11	31	04	Cloudy, frost, becoming brighter, with sunny intervals, rain at night
12	01	06	Bright and sunny, slight rain at night
13	CALM		Cloudy, rain
14	11	04	Cloudy, slight drizzle, dull damp day
15	09	11	Rain, continuous and heavy all day
16	01	04	Cloudy, rain at night
17	05	09	Rain, continuous and heavy all day
18	35	03	Cloudy, showers
19	CALM		Bright and sunny, ground frost
20	24	02	Cloud, rain becoming brighter, sunny intervals
21	14	02	Bright and sunny at first becoming cloudy w. showers & sunny int-ervals
22	27	10	Bright and sunny, showers
23	22	02	Ground frost, bright and sunny, with heavy showers
24	CALM		Fog at first, rain, dull damp day
25	18	01	Fog at first, becoming brighter with sunny intervals
26	23	04	Bright and sunny, slight ground frost
27	CALM		Bright and sunny, becoming cloudy
28	20	05	Bright and sunny at first, becoming cloudy, rain
29	23	06	Bright and sunny, ground frost
30	23	14	Cloudy, strong SW wind, with sunny intervals
MEAN	5.6 knots		
AVERAGE	8.1 knots		

DAILY OBSERVATIONS AND WEATHER MAY 1986

DATE	TEMPERATURE °C							RAIN-FALL	SUN-SHINE	State of ground	Cloud	Present weather	Visibility
	Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	mm.	hours				
1	12.5	10.0	19.9	7.4	3.9	7.6	6.6		11.8	0	2	01	6
2	13.7	10.1	17.5	6.0	2.3	9.0	6.8		10.0	0	1	02	6
3	11.9	10.6	13.6	4.6	2.2	9.6	6.9	tr	4.5	0	6	42	4
4	12.7	9.1	13.7	4.8	1.5	9.8	7.1	5.6	7.9	0	3	01	6
5	7.8	7.5	10.8	7.1	5.5	9.6	7.3	6.4	0.0	1	7	64	5
6	10.7	9.0	15.5	4.4	1.5	9.1	7.5	20.4	9.6	1	2	01	6
7	7.1	6.3	11.4	5.7	5.0	9.5	7.5	4.0	1.0	2	8	65	6
8	10.5	8.5	13.6	4.7	2.1	9.2	7.5	2.4	5.3	2	7	03	6
9	9.9	8.5	14.5	5.5	1.5	9.2	7.5	0.2	2.0	2	8	03	5
10	13.9	11.8	15.4	9.7	8.2	9.5	7.7		6.7	1	7	01	6
11	11.3	9.8	14.0	9.1	7.1	9.8	7.9	1.7	6.3	0	5	01	7
12	13.5	10.9	15.4	8.7	7.4	9.9	7.9		5.9	1	5	02	7
13	10.0	7.4	11.5	7.5	5.5	10.0	7.9		11.1	1	5	02	6
14	9.4	9.2	12.4	4.6	1.3	9.6	7.8	0.5	5.8	0	6	03	6
15	8.4	6.2	13.0	4.7	2.0	9.6	7.8	3.6	4.8	0	7	03	6
16	11.4	8.0	14.6	3.7	0.1	9.4	8.3	tr	9.6	1	2	01	7
17	10.3	7.2	13.8	5.5	2.3	10.0	8.3	1.2	1.2	1	8	03	6
18	12.2	9.9	14.5	9.8	8.3	10.1	8.5		5.5	0	5	01	7
19	14.1	11.2	17.5	8.7	4.5	10.3	8.5	4.6	10.6	0	4	01	7
20	10.4	10.1	14.1	5.4	2.0	10.8	8.7	8.6	0.0	2	8	65	5
21	9.9	9.3	13.4	7.9	5.0	10.6	8.7	1.0	6.8	2	8	65	5
22	10.1	7.6	14.0	5.6	3.0	10.3	8.7	0.3	1.2	1	3	01	7
23	10.0	9.0	14.5	6.2	3.1	10.2	8.7		9.1	2	6	03	6
24	12.5	10.0	14.5	7.3	4.0	10.2	8.9	0.9	9.7	1	4	03	7
25	14.0	11.4	16.6	8.7	7.0	10.6	9.0	0.1	11.0	1	5	03	7
26	13.9	9.8	15.3	11.4	9.2	11.3	9.0		9.4	0	3	03	7
27	11.6	8.5	12.3	7.4	4.1	11.4	9.0	tr	7.7	0	6	03	7
28	11.0	7.9	13.2	5.1	1.1	10.7	9.0	0.1	8.1	0	4	01	7
29	12.1	8.5	15.3	5.2	0.9	10.7	9.4	0.4	5.5	0	3	02	7
30	12.0	7.7	13.5	6.0	2.9	11.1	9.4	3.1	4.1	0	6	03	7
31	12.0	11.4	16.8	8.0	6.5	11.1	9.4	0.4	0.1	1	8	02	6
MONTH	11.3	9.1	14.4	6.7	3.9	10.0	8.2	65.5	192.3		5.2		
AVERAGE			14.8	5.5				54.1	159.96				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
65.5mm	121%	192.3 hours	120%	39%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	24	04	Bright and sunny all day. Warm and dry
2	CALM		Bright and sunny. Warm dry day
3	04	03	Cloudy with sunny intervals
4	17	08	Bright and sunny
5	12	10	Rain, heavy at times
6	19	06	Bright and sunny, heavy overnight rain
7	22	05	Rain becoming brighter by late afternoon, rain at night + thunder-storm
8	22	05	Bright and sunny at first becoming cloudy with rain
9	21	03	Bright and sunny at first becoming cloudy with sunny intervals & showers
10	25	20	Bright and sunny. Strong SW wind
11	27	16	Bright and sunny intervals
12	24	15	Rain at first becoming bright w. sunny intervals. Strong SW wind
13	25	15	Bright and sunny at first, becoming cloudy, strong SW wind, cont. sunny intervals
14	24	09	Bright at first becoming cloudy, sunny intervals and showers
15	33	08	Cloudy, sunny intervals and showers
16	33	07	Bright and sunny, warm dry day
17	17	06	Bright at first, becoming cloudy with sunny intervals & showers
18	25	26	Sunny intervals, warm dry day
19	23	06	Bright and sunny, warm dry day
20	CALM		Cloudy at first, rain heavy, thunderstorm at night
21	21	11	Rain at first, SW wind, becoming brighter w sunny intervals
22	22	20	Bright and sunny, showers. Strong SW wind
23	25	12	Bright and sunny, showers. Strong SW wind continuing
24	25	13	Bright and sunny, strong SW wind
25	23	14	Brignt and sunny, continuing windy
26	28	07	Bright and sunny becoming cloudy with sunny intervals
27	24	16	Cloudy, strong SW wind. Wind moderating at night
28	31	08	Bright and sunny, showers with sunny intervals
29	34	04	Bright and sunny at first becoming cloudy w sunny intervals & show-ers
30	30	01	Bright and sunny at first becoming cloudy w sunny intervals
31	33	01	Rain at first, cloudy
MEAN		9 knots	
AVERAGE		7.0 knots	

DAILY OBSERVATIONS AND WEATHER JUNE 1986

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	16.2	15.4	19.3	11.5	10.5	11.7	9.5	Tr	0.8	1	7	02	5
2	15.8	13.3	20.5	11.8	9.2	12.5	9.5	2.5	4.6	1	6	01	6
3	13.0	11.5	14.5	12.1	11.5	13.5	9.7	3.1	1.2	1	8	03	6
4	10.9	7.7	14.4	5.3	3.4	12.7	10.0	2.1	9.2	1	5	01	7
5	8.3	6.1	13.2	3.5	0.5	12.5	10.1	0.2	4.8	1	6	03	6
6	8.7	7.8	14.6	6.2	5.5	12.3	10.0		0.7	1	8	60	6
7	14.6	11.0	18.1	3.4	0.7	11.9	10.3		5.8	0	4	03	6
8	12.5	8.6	17.4	6.4	4.1	12.3	10.3	0.4	7.9	0	3	01	7
9	17.0	16.0	18.0	9.8	8.6	12.5	10.3	15.8	5.4	0	6	03	7
10	9.9	9.5	13.5	8.0	7.6	12.4	10.4	1.3	4.4	2	8	65	5
11	12.0	8.7	14.5	5.4	2.5	12.0	10.5	0.7	8.7	1	4	01	7
12	13.1	9.9	16.8	4.8	2.8	12.2	10.6	Tr	3.4	1	6	03	7
13	15.2	13.5	19.2	11.6	9.0	12.4	10.6		3.9	0	8	60	6
14	17.7	15.4	23.7	11.8	8.5	12.9	10.8		11.1	0	1	01	7
15	20.0	15.0	20.2	9.5	6.6	14.3	10.7		13.1	0	1	02	7
16	18.0	15.1	21.2	8.6	5.4	14.6	10.9		11.5	0	0	02	7
17	20.7	18.7	24.5	12.5	10.0	15.5	11.1	0.7	5.1	0	6	03	5
18	10.3	10.1	17.0	9.7	9.3	15.5	11.1	1.6	0.0	1	8	63	4
19	12.8	11.1	14.6	6.5	3.0	14.4	11.5		3.5	1	8	02	6
20	10.0	8.5	13.5	8.0	7.6	14.4	11.5		0.2	0	8	02	6
21	13.4	10.5	14.2	7.7	7.1	14.0	11.5	1.1	8.1	0	4	01	7
22	12.1	11.3	14.0	7.6	7.0	14.4	11.5	Tr	0.1	1	7	03	6
23	10.4	9.0	12.7	8.0	7.4	14.3	11.9	2.1	0.2	0	8	02	6
24	12.5	11.4	18.4	8.8	8.4	14.0	12.0	0.5	2.3	1	8	02	6
25	16.8	14.5	21.5	12.0	10.0	14.0	12.0		10.4	0	4	01	6
26	19.9	15.9	23.5	13.3	9.8	14.9	12.0		12.8	0	3	01	7
27	19.2	16.4	23.3	9.0	5.5	15.4	12.2		10.8	0	1	02	7
28	20.2	15.9	25.2	13.5	10.2	16.1	12.3		12.9	0	1	02	7
29	20.8	15.3	23.2	10.0	6.2	16.5	12.4		12.3	0	1	02	6
30	13.4	12.3	17.9	11.0	5.9	16.5	12.4		4.3	0	8	03	6
MONTH	14.5	12.2	18.1	8.9	6.8	13.8	11.0	32.1	179.5		5		
AVERAGE			17.9	8.5				50.0	174.6				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
32.1 mm	64.2%	179.5 hours	102.8%	35%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	C A L M		Cloudy, warm day, slight rain
2	32	02	Bright and sunny at first. Warm, dry day. Rain at night
3	29	05	Cloudy with sunny intervals. Rain at night
4	32	07	Bright and sunny becoming cloudy with sunny intervals and showers
5	35	10	Cloudy with sunny intervals. Showers
6	01	05	Cloudy. Slight rain at times
7	34	04	Bright and sunny. Warm dry day
8	29	08	Bright and sunny. Rain at night
9	22	15	Bright and sunny at first becoming cloudy. Strong SW wind
10	C A L M		Rain clearing by afternoon becoming brighter
11	34	03	Bright and sunny
12	21	14	Bright at first becoming cloudy with showers
13	24	04	Bright at first. Cloudy with showers
14	23	05	Dry warm and sunny
15	08	02	Bright and sunny. Warm dry day
16	07	04	Bright and sunny, warm and dry
17	C A L M		Bright at first becoming cloudy
18	C A L M		Rain clearing by afternoon. Dull, cool cloudy
19	09	05	Cloudy with sunny intervals
20	07	07	Cloudy dry day
21	06	08	Bright and sunny. Rain at night
22	07	04	Cloudy cool day
23	06	04	Cloudy. Rain at night
24	22	05	Cloudy with sunny intervals
25	22	10	Bright and sunny
26	16	06	Bright and sunny. Warm and dry
27	11	01	Bright, sunny warm, dry day
28	19	02	Bright, sunny, warm and dry
29	10	04	Continuing dry, warm and sunny
30	09	04	Cloudy becoming brighter late afternoon
MEAN	4.9 knots		
AVERAGE	6.3 knots		

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	17.1	15.0	22.6	12.1	8.4	16.5	12.4		3.7	0	8	02	6
2	19.3	15.5	23.5	10.3	6.1	16.6	12.5		8.2	0	6	03	7
3	19.8	15.2	21.5	11.7	7.9	16.9	13.0		8.2	0	4	03	7
4	15.1	13.0	19.6	14.1	12.0	16.7	13.2		3.8	0	7	02	7
5	14.2	11.9	19.1	10.3	6.2	16.0	13.3		1.3	0	7	02	7
6	16.9	12.2	18.0	10.9	5.8	15.9	13.4		3.6	0	6	02	7
7	15.0	10.2	17.4	8.5	4.5	15.3	13.4	0.2	10.9	1	3	01	7
8	13.4	12.1	18.4	10.6	8.4	15.1	13.4	Tr	4.3	0	8	62	6
9	14.4	10.0	16.7	7.6	3.8	15.2	13.4	Tr	3.7	0	6	02	7
10	16.3	12.6	18.8	10.9	8.3	15.0	13.4		5.4	0	6	02	7
11	15.0	12.0	16.9	7.3	2.8	15.2	13.4		7.2	0	6	02	7
12	13.9	12.0	16.3	10.9	9.1	15.3	13.4		0.0	0	7	02	5
13	16.2	14.3	20.7	9.8	6.2	15.1	13.4		0.4	0	7	02	6
14	20.5	18.0	26.0	13.8	10.5	15.5	13.5		8.3	0	6	01	6
15	21.5	18.6	24.0	16.6	13.9	16.8	13.5		0.1	0	7	02	7
16	23.7	18.0	26.6	16.6	13.5	17.0	13.5		8.9	0	3	01	7
17	14.6	11.4	17.7	11.1	7.3	16.5	13.6		5.3	0	6	03	7
18	16.0	12.5	16.9	8.6	4.0	15.5	13.8		2.4	0	6	02	7
19	14.0	11.3	17.1	9.3	5.5	15.3	13.8	1.6	1.3	0	8	03	7
20	15.2	12.2	21.1	11.8	10.4	15.2	13.9		11.5	0	4	01	7
21	15.5	12.3	18.5	9.0	3.8	15.5	13.7	Tr	3.2	0	5	03	7
22	14.4	10.8	15.7	7.8	3.9	15.0	13.7	1.4	1.5	0	6	03	7
23	14.3	11.3	16.5	8.9	7.4	14.8	13.7	6.2	5.4	0	5	02	7
24	16.1	11.8	19.5	7.9	3.7	14.6	13.7	0.5	7.8	1	2	01	7
25	15.4	12.5	18.2	12.0	9.1	15.0	13.7		6.5	0	6	03	6
26	16.3	14.3	18.6	10.9	7.9	15.2	13.7		2.1	0	6	02	7
27	16.4	12.9	18.2	8.8	6.0	15.0	13.6		2.0	0	6	02	7
28	17.2	14.1	21.0	13.7	9.5	14.8	13.6	5.1	1.5	0	6	02	7
29	16.6	15.6	17.0	14.5	12.2	15.3	13.5	0.9	0.1	1	8	03	7
30	12.5	11.6	16.5	7.6	3.9	14.6	13.5	5.0	0.2	1	8	02	6
31	16.0	13.5	17.8	11.5	9.0	14.5	13.5	3.3	4.6	1	5	01	7
MONTH	16.2	13.2	19.2	10.8	7.5	15.5	13.5	24.2	133.4		5.9		
AVERAGE			19.4	10.4				65.8	159.34				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
24.2 mm	37%	133.4 hours	84%	26%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	C A L M		Cloudy, becoming brighter w sunny intervals, warm day
2	C A L M		Bright and sunny, becoming cloudy
3	33	06	Bright and sunny, becoming cloudy
4	25	11	Cloudy with sunny intervals
5	29	08	Cloudy with sunny intervals
6	31	06	Bright and sunny , becoming cloudy
7	31	13	Bright and sunny, cool NW breeze
8	34	02	Cloudy, showers, becoming brighter with sunny intervals
9	31	08	Bright and sunny, becoming cloudy
10	34	06	Bright and sunny, becoming cloudy with sunny intervals
11	09	04	Bright and sunny, becoming cloudy
12	16	01	Cloudy, dry day
13	22	01	Cloudy with sunny intervals
14	34	05	Bright and sunny, warm dry day
15	24	06	Cloudy warm day
16	22	10	Bright and sunny, S westerly breeze, warm dry day
17	29	11	Sunny intervals, becoming cloudy, west wind, dry day
18	35	07	Bright at first, becoming cloudy, dry day
19	25	04	Cloudy, sunny intervals, rain at night
20	30	14	Bright and sunny. Warm dry day
21	29	08	Bright at first, becoming cloudy, light shower in evening
22	31	08	Cloudy, cooler than of late, cloudy all day exc. evening sun
23	33	05	Bright with sunny intervals and showers
24	29	03	Bright and sunny, rain late afternoon
25	33	11	Cloudy, becoming brighter with sunny intervals
26	22	03	Bright at first, becoming cloudy
27	24	14	Bright at first, becoming cloudy
28	25	07	Cloudy with sunny intervals and rain at times
29	26	04	Cloudy, showers
30	18	02	Cloudy, rain, heavy at times
31	22	07	Bright and sunny at first, becoming cloudy, sunny intervals
MEAN		6.3 knots	
AVERAGE		6.1 knots	

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	14.1	10.1	16.8	8.2	5.0	14.3	13.5	6.2	6.6	1	3	01	7
2	14.7	12.9	16.3	11.4	11.0	14.6	13.5	Tr	2.1	1	7	03	7
3	16.1	12.1	16.8	10.0	7.0	13.9	13.5	1.3	4.2	0	4	01	7
4	13.8	12.5	16.2	9.4	7.9	14.0	13.5	1.0	1.2	1	7	01	6
5	14.9	12.6	17.9	9.6	5.6	14.2	13.5	2.9	7.1	1	6	01	7
6	12.0	11.6	16.1	10.1	8.0	14.4	13.5	7.2	0.7	2	8	63	5
7	14.6	13.5	16.7	12.0	10.5	14.4	13.4	2.7	1.4	1	8	02	6
8	15.4	12.6	16.8	10.8	8.1	14.5	13.5	0.1	3.4	1	5	03	7
9	15.5	11.9	20.5	7.1	3.1	14.2	13.4		10.7	1	4	03	7
10	15.5	13.5	18.0	8.9	5.6	14.7	13.4		9.6	1	5	02	7
11	13.2	11.6	15.2	6.7	2.5	14.9	13.4		0.2	1	8	02	7
12	14.9	12.3	16.9	10.0	8.7	14.6	13.4		6.0	0	4	03	6
13	12.9	11.5	16.5	11.2	8.6	14.8	13.4	2.5	0.0	0	8	02	6
14	16.2	14.0	19.5	12.8	11.4	14.8	13.5		4.4	1	5	01	7
15	13.2	10.6	16.9	10.6	6.5	14.9	13.5	Tr	7.0	0	7	02	7
16	12.1	10.6	18.1	8.7	5.5	14.5	13.5		4.5	1	8	61	7
17	16.1	13.5	17.9	11.0	7.5	14.3	13.5	0.2	2.5	0	6	02	7
18	13.4	12.6	13.8	9.4	5.1	14.4	13.5	13.2	0.0	0	8	03	6
19	11.2	11.2	14.5	10.3	9.9	14.1	13.5	4.3	0.0	2	8	60	5
20	14.3	12.1	16.6	6.3	1.5	13.7	13.4	0.1	6.0	2	4	01	6
21	13.0	11.2	15.0	4.3	1.6	13.8	13.4	5.3	0.3	1	5	02	6
22	10.1	10.1	11.9	9.7	9.1	13.8	13.4	2.3	0.0	2	8	63	4
23	10.6	10.3	15.2	6.0	0.5	13.2	13.3	0.2	3.5	2	6	02	6
24	12.1	10.4	16.0	4.5	0.0	13.0	13.4		6.0	1	7	02	6
25	12.5	11.1	14.0	2.8	-0.9	13.0	13.2	69.1	3.9	1	4	01	5
26	11.1	11.1	11.5	9.3	7.8	12.6	13.2	27.7	0.0	2	8	65	5
27	10.5	10.0	13.0	9.4	7.9	12.3	13.0	9.5	0.0	2	8	63	5
28	13.0	10.9	16.1	7.8	4.5	12.3	13.0	1.3	8.3	2	3	01	6
29	10.0	9.5	12.4	9.1	6.9	12.7	13.1	1.3	0.0	1	8	64	6
30	12.2	10.5	14.1	8.5	5.7	12.5	12.8		4.7	1	5	01	6
31	12.6	9.0	17.0	4.4	0.1	12.5	12.8	10.7	7.7	1	2	01	7
MONTH	13.3	11.5	15.9	8.7	5.9	13.9	13.3	169.1	112.1		6.0		
AVERAGE			19.0	10.2				68.8	146.94				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
169.1 mm	246%	112.1 hours	76%	24%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	31	06	Bright and sunny becoming cloudy with rain at night
2	22	17	Cloudy, strong SW wind, sunny intervals, rain
3	25	08	Bright and sunny, becoming cloudy
4	C A L	M	Cloudy with a little sunshine and showers
5	23	05	Cloudy becoming bright and sunny
6	20	05	Rain, clearing late afternoon, evening sunshine, thunderstorms
7	20	03	Cloudy day with sunny spells and showers
8	33	10	Bright and sunny at first becoming cloudy
9	35	02	Bright and sunny
10	09	04	Cloudy at first, becoming bright and sunny
11	07	04	Cloudy dry day
12	C A L	M	Bright and sunny, becoming cloudy with sunny periods
13	18	02	Cloudy day, rain at times
14	25	06	Cloudy dry day with sunny periods
15	23	16	Cloudy, fresh SW wind, sunny periods
16	25	18	Cloudy, fresh SW to W wind, some light rain becoming sunny later
17	32	05	Cloudy with sunny intervals
18	08	02	Cloudy, rain at night
19	C A L	M	Cloudy, slight rain at first, showers
20	01	03	Bright and sunny
21	C A L	M	Bright at first becoming cloudy, rain
22	07	06	Rain
23	01	06	Sunny intervals and showers
24	02	09	Cloudy, becoming brighter
25	C A L	M	Bright and sunny becoming cloudy by afternoon with strong winds, heavy rain
26	07	15	Strong NE wind, heavy rain
27	33	12	Rain, heavy at times, strong NW wind
28	34	09	Bright and sunny with showers
29	32	07	Cloudy, rain
30	35	12	Bright and sunny with rain at night
31	C A L	M	Bright and sunny, heavy rain at night
MEAN	6.16 knots		
AVERAGE	5.4 knots		

DAILY OBSERVATIONS AND WEATHER SEPTEMBER 1986

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	15.5	12.1	18.9	9.3	6.9	13.0	12.8		10.6	2	1	01	7
2	13.0	10.9	15.5	10.8	7.5	13.8	12.7	22.1	0.8	0	7	03	7
3	10.0	9.5	13.2	8.2	7.0	12.9	12.5	0.4	2.6	2	7	64	6
4	12.6	9.9	15.8	5.5	1.0	12.5	12.7		7.0	1	6	03	7
5	15.1	12.0	17.9	10.1	4.9	12.6	12.7		8.0	1	3	01	7
6	12.4	10.2	15.6	9.4	4.1	12.9	12.7		6.5	1	3	02	7
7	12.5	9.9	15.3	7.4	4.6	12.8	12.6		3.8	0	5	03	7
8	12.6	10.0	15.5	7.2	3.5	12.6	12.6		9.6	0	2	01	7
9	11.9	9.6	15.0	2.8	-2.0	12.5	12.6		6.7	0	3	02	7
10	9.1	7.2	15.4	2.6	-2.2	12.3	12.5		9.7	0	5	03	6
11	11.0	8.9	14.7	1.0	-3.0	12.1	12.5		9.2	0	1	01	6
12	11.3	9.8	13.0	2.6	-2.1	12.0	12.5	0.3	2.0	0	3	02	6
13	10.4	7.9	14.9	1.6	-2.7	11.5	12.4		11.1	0	6	02	7
14	11.1	9.5	14.9	2.3	-2.0	11.6	12.4		7.3	0	5	02	6
15	10.7	8.1	13.7	3.2	-2.5	11.5	12.4		9.2	0	4	02	7
16	10.1	8.3	14.0	2.9	-1.0	11.4	12.3		9.0	0	2	01	7
17	12.0	9.9	13.9	2.1	-2.5	11.4	12.3	3.4	4.5	0	2	02	7
18	11.5	9.6	14.0	4.7	-0.1	11.2	12.3	Tr	9.1	1	1	02	7
19	10.6	9.1	17.3	2.0	-2.0	11.1	12.0		8.8	1	1	02	7
20	17.3	14.9	20.2	9.4	4.9	11.4	12.1		8.4	0	2	02	6
21	14.1	12.1	15.9	11.0	7.2	12.1	12.0	1.8	2.2	0	5	03	7
22	14.9	13.8	17.0	12.3	9.7	12.2	12.0		0.3	1	7	03	7
23	14.8	13.5	17.2	12.0	7.0	12.4	11.9		2.7	1	4	01	7
24	11.3	10.9	15.1	8.6	3.9	12.5	11.9		3.2	0	8	03	6
25	10.5	8.7	16.9	1.9	-1.5	12.0	12.0		10.2	0	2	01	7
26	8.5	8.0	15.1	2.8	-0.2	11.9	12.0		2.0	0	5	01	5
27	10.9	9.8	17.4	4.8	1.1	11.9	12.0		3.1	0	4	02	5
28	17.4	16.1	19.6	10.8	8.9	12.2	12.0		7.5	0	5	02	6
29	19.1	17.6	20.3	13.2	9.5	12.7	12.0		8.2	0	3	01	7
30	17.9	15.6	23.5	9.1	5.2	12.7	12.0		9.4	0	0	01	7
MONTH	12.7	10.8	16.2	6.4	2.4	12.2	12.3	28.0	192.7		3.7		
AVERAGE			16.9	8.5				50.6	126.0				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
28 mm	55%	192.7 hours	153%	50.6%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	30	10	Bright and sunny, warm dry day
2	29	15	Bright at first becoming cloudy with a W-NW wind, heavy rain/night
3	35	12	Heavy rain, sunny intervals
4	26	11	Bright and sunny becoming cloudy with sunny intervals
5	29	12	Bright and sunny with a west wind
6	31	12	Bright and sunny, NW wind
7	30	14	Cloudy with sunny intervals
8	35	06	Bright and sunny, warm dry day
9	24	01	Ground frost, bright and sunny
10	CALM		Ground frost, bright and sunny, warm dry day
11	CALM		Ground frost, bright and sunny, warm dry day
12	01	06	Ground frost, bright and sunny, rain in afternoon
13	24	03	Ground frost, bright and sunny
14	02	06	Ground frost, bright and sunny, dry sunny day
15	02	06	Ground frost, bright and sunny, dry sunny day
16	03	04	Ground frost, bright and sunny, dry sunny day
17	04	05	Ground frost, bright and sunny, becoming cloudy w. heavy showers
18	35	05	Ground frost, bright and sunny
19	23	05	Ground frost, bright and sunny
20	28	08	Ground frost, bright and sunny
21	31	16	Cloudy with sunny intervals, rain at night
22	22	03	Cloudy with sunny intervals
23	01	03	Cloudy, becoming brighter with sunny intervals
24	CALM		Cloudy, becoming brighter with sunny intervals
25	22	04	Ground frost, bright and sunny, warm dry day
26	CALM		Cloudy at first, becoming brighter
27	22	04	Bright and sunny, becoming cloudy in afternoon
28	25	15	Bright and sunny, dry day
29	32	05	Bright and sunny, warm dry day
30	23	05	Bright and sunny, warm dry day
MEAN		6.53 knots	
AVERAGE		6.8 knots	

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	13.7	12.5	16.5	8.7	5.5	13.0	12.1		6.9	0	2	02	7
2	11.6	11.2	14.6	9.4	3.5	12.9	12.1		1.4	0	8	03	6
3	14.0	12.8	12.8	6.7	2.2	12.4	12.1		9.0	0	3	01	7
4	12.3	11.1	16.2	7.7	3.5	12.5	12.1	0.4	8.2	0	1	01	6
5	11.6	11.4	17.1	10.4	6.9	12.5	12.2		2.5	1	7	03	4
6	15.5	15.3	18.5	11.3	6.6	12.6	12.2		4.4	0	6	01	7
7	15.0	15.0	18.6	13.1	7.4	12.8	12.3		6.4	0	8	03	6
8	13.0	10.8	17.1	5.5	1.2	12.6	12.3		5.7	0	3	01	6
9	14.0	13.0	15.6	12.5	8.8	12.7	12.3		0.0	0	8	03	6
10	11.4	10.1	14.5	10.5	6.9	12.7	12.3		1.4	0	8	02	6
11	11.9	9.6	15.5	4.0	1.6	12.0	12.3		6.8	0	0	01	7
12	6.1	5.5	14.5	2.2	-0.5	11.4	12.3		8.4	1	1	02	5
13	11.4	11.1	13.5	5.9	1.1	11.4	12.0		0.0	0	9	43	1
14	11.8	11.6	16.1	10.0	6.4	11.6	12.0	1.3	1.0	0	9	43	2
15	10.4	8.3	15.1	3.3	-2.5	11.4	12.0		8.6	1	1	01	6
16	10.8	9.1	15.5	3.7	-1.0	10.9	12.0		5.6	1	0	01	6
17	7.2	6.2	14.2	1.5	-2.2	10.3	12.0	0.2	8.9	1	1	02	6
18	7.4	7.1	10.7	4.6	-1.1	10.1	11.7	4.2	0.0	1	7	62	5
19	6.3	5.8	8.5	2.3	-1.9	9.8	11.7	3.1	8.2	1	3	01	7
20	4.8	4.6	8.6	2.5	-2.5	9.0	11.4	3.2	2.5	2	8	65	5
21	8.0	7.1	10.2	4.2	1.1	8.7	11.3	0.1	1.0	2	8	62	6
22	8.0	7.7	9.5	4.5	-0.5	8.7	11.2	0.1	7.8	1	1	01	7
23	6.6	5.5	10.0	2.9	-1.9	8.3	11.1	Tr	8.3	1	1	01	7
24	6.1	5.6	10.6	3.4	-1.2	8.0	10.9	0.9	0.1	1	8	03	6
25	10.6	8.9	11.5	6.1	5.0	8.5	10.7	0.5	1.6	1	8	02	7
26	8.9	7.2	12.0	5.6	1.9	8.5	10.5	0.8	6.9	1	1	02	7
27	11.1	10.7	15.1	5.7	5.4	8.7	10.5	2.6	0.1	1	8	62	6
28	13.0	12.9	15.8	10.7	6.6	9.4	10.4	0.5	1.3	2	8	63	5
29	8.1	6.1	10.7	4.6	-0.1	9.4	10.4	0.4	7.3	1	1	01	7
30	10.5	8.5	11.1	7.3	4.0	9.0	10.2	0.5	6.3	1	5	03	6
31	7.1	6.5	10.0	4.7	1.2	8.6	10.2	12.2	1.9	1	6	02	6
MONTH	10.3	9.3	13.7	6.3	2.3	10.7	11.6	31.0	138.5		4.8		
AVERAGE			13.2	6.2				64.3	91.76				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
31.0 mm	48%	138.5 hours	151%	42.6%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	22	08	Bright and sunny
2	24	03	Cloudy becoming brighter by late afternoon
3	25	04	Bright and sunny; dry day
4	21	04	Bright and sunny, rain at night
5	24	08	Cloudy becoming brignter with sunny intervals
6	27	07	Bright and sunny, becoming cloudy with sunny intervals
7	25	05	Cloudy, becoming brighter with sunny intervals
8	C A L M		Bright and sunny intervals
9	24	06	Cloudy dry day
10	24	03	Cloudy becoming brighter with sunny intervals
11	25	04	Bright and sunny intervals
12	22	01	Bright sunny day. Ground frost
13	21	06	Fog
14	21	05	Fog, dull damp day with rain
15	30	04	Bright and sunny, ground frost, dry bright day
16	C A L M		Ground frost, bright and sunny, dry bright day
17	22	03	Ground frost, bright and sunny, dry bright day
18	21	08	Ground frost. Cloudy, rain at night
19	24	04	Bright and sunny, ground frost, rain at night
20	C A L M		Rain, ground frost, becoming brighter with sunny intervals & showers
21	25	07	Rain at first, becoming brignter, sunny intervals & snowers
22	27	11	Bright and sunny, ground frost and showers
23	33	15	Ground frost, bright and sunny
24	20	04	Ground frost, cloudy
25	23	17	Cloudy with a little sunshine and showers. Strong W to NW wind
26	31	12	Bright and sunny
27	22	15	Rain, strong S-SW wind, clearing by afternoon
28	20	06	Rain, clearing to give sunny intervals
29	22	07	Ground frost, bright and sunny
30	25	13	Bright and sunny. SW wind, rain at night
31	25	03	Cloudy
MEAN		6.2	
AVERAGE		6.9 knots	

DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SUN-SHINE hours	State of ground	Cloud	Present weather	Visibility
1	6.9	6.5	8.1	3.9	3.1	8.4	10.3	1.5	1.4	1	6	62	6
2	3.8	2.5	9.0	1.9	-1.7	8.1	10.2	0.1	5.3	1	3	01	6
3	8.6	6.5	11.4	3.3	-0.3	7.9	10.2		6.9	1	1	02	6
4	7.5	6.2	12.5	3.4	-3.1	7.7	10.1	0.4	3.5	1	4	02	6
5	10.4	9.1	13.5	7.1	5.6	8.0	10.1		2.6	1	6	03	6
6	8.3	6.1	12.4	4.1	-1.2	8.0	10.1		4.3	1	1	01	7
7	12.3	11.2	14.2	5.2	2.1	7.9	9.8	1.2	1.1	1	8	03	6
8	5.9	3.8	8.5	3.5	0.0	8.4	9.6	4.3	7.4	1	1	01	7
9	7.9	6.3	11.6	5.0	1.0	8.0	9.6	3.8	0.0	1	8	03	6
10	11.5	8.6	11.7	6.7	6.0	8.4	9.7	0.3	5.4	2	3	01	6
11	7.5	7.4	10.3	6.2	3.1	8.2	9.5	Tr	1.7	2	7	01	5
12	4.4	3.7	11.1	2.3	-3.1	7.5	9.3	4.0	0.1	1	7	02	5
13	11.0	10.5	11.6	4.1	3.0	7.5	9.4	5.4	0.0	1	8	50	5
14	6.5	6.5	10.4	5.4	1.0	8.0	9.4	5.4	0.0	2	8	02	5
15	6.5	5.9	10.5	5.5	1.5	8.0	9.4	Tr	7.0	1	3	02	6
16	10.1	8.5	10.9	5.6	0.6	7.9	9.3		1.5	1	7	02	7
17	3.2	2.8	6.7	1.0	-3.9	7.4	9.2	0.7	2.3	4	3	01	6
18	4.5	3.5	6.6	1.8	-1.7	6.8	9.0	6.8	2.9	2	6	03	6
19	4.0	3.6	8.5	3.3	1.3	6.5	9.0	0.1	4.5	2	2	01	6
20	4.3	3.2	7.1	2.2	-2.5	6.3	8.9		6.9	4	1	02	6
21	1.4	1.0	7.4	-0.4	-6.0	5.9	8.8	2.4	4.8	4	2	02	5
22	6.2	5.5	8.1	1.1	-2.1	5.7	8.7	2.1	4.2	2	4	62	6
23	8.0	6.5	10.1	3.2	1.2	5.9	8.5	Tr	2.6	2	6	03	6
24	10.0	8.7	13.6	5.6	3.5	6.0	8.4	Tr	1.9	1	7	02	6
25	13.5	12.2	14.0	9.4	7.5	7.0	8.6	1.6	0.0	1	8	03	6
26	6.0	4.5	9.5	3.5	-1.5	7.4	8.7	1.0	5.4	2	2	01	6
27	9.4	8.9	10.7	4.4	-1.7	6.8	8.3		0.0	1	7	03	6
28	9.9	9.0	10.5	8.0	7.2	7.2	8.4		0.2	1	7	02	6
29	8.9	8.1	11.1	7.9	5.0	7.4	8.1		5.4	1	3	01	5
30	7.4	6.2	12.2	3.8	1.6	7.4	8.3		0.3	1	4	03	5
MONTH	7.5	6.4	10.5	4.3	0.85	7.4	9.2	36.2	89.6		4.8		
AVERAGE			8.9	3.0				56.9	58.8				

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
36.2mm	64%	89.6 hours	152%	35%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	04	14	Rain, heavy at times with sunny intervals
2	32	02	Bright and sunny, ground frost
3	26	04	Ground frost, bright and sunny
4	25	03	Ground frost, cloudy becoming brighter with sunny intervals
5	25	19	Cloudy with sunny intervals, dry day
6	29	07	Ground frost, bright with sunny intervals
7	21	10	Cloudy, strong SW wind, sunny intervals
8	29	14	Bright and sunny. Strong SW wind, Sunny intervals, rain
9	20	09	Cloudy, rain
10	24	24	Bright and sunny, showery, strong winds, rain at night
11	24	03	Rain at first, cloudy, becoming brighter late afternoon
12	23	05	Ground frost, cloudy
13	21	12	Cloudy, slight rain at first, S-SW wind, heavy showers
14	20	03	Cloudy with rain
15	22	06	Sunny dry day
16	21	16	Cloudy at first becoming brighter with sunny intervals
17	20	05	Ground frost, bright and sunny at first becoming cloudy, rain
18	22	03	Ground frost, cloudy, sunny intervals, rain at night
19	29	03	Bright and sunny
20	31	05	Ground frost, bright and sunny
21	35	03	Frost, bright and sunny
22	23	12	Cloudy, slight rain at first, ground frost, becoming brighter with with sunny intervals. Heavy rain at night
23	27	14	Cloudy at first, becoming brighter with sunny intervals
24	25	08	Cloudy, mild, becoming brighter, sunny intervals, strong SW wind
25	23	16	Cloudy, strong SW wind, mild, rain at night
26	17	04	Ground frost, bright and sunny and showers
27	22	06	Ground frost, cloudy mild day
28	21	05	Cloudy, mild dry day
29	24	12	Cloudy at first, becoming brighter with sunny intervals, dry day
30	25	12	Cloudy
MEAN		8.6 knots	
AVERAGE		8.0 knots	

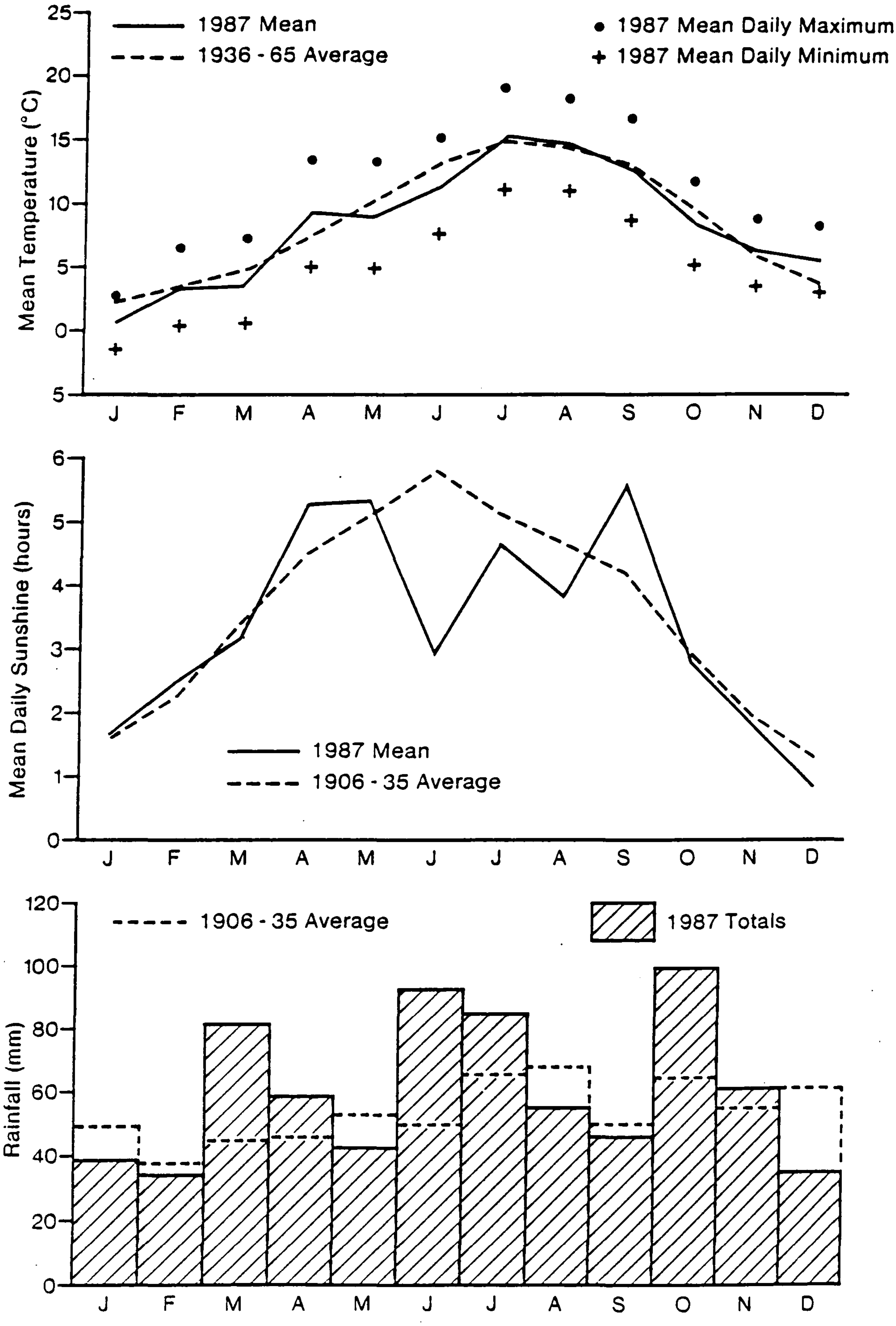
DATE	TEMPERATURE °C Dry bulb	Wet bulb	Maximum	Minimum	Grass min.	30 cm. Earth under grass	100 cm. Earth under grass	RAIN-FALL mm.	SNOW cm. Lying 0900 hours	SUN-SHINE hours	State of ground without snow	State of ground with snow	Cloud	Present weather	Visibility
1	12.0	11.5	13.0	4.3	3.0	7.2	8.3			3.8	1		7	03	6
2	5.8	5.6	12.8	5.2	1.5	7.2	8.3	0.4		0.0	1		8	02	6
3	12.8	11.2	13.7	5.7	4.5	7.5	8.4	0.2		0.0	1		8	03	6
4	8.7	7.5	13.8	7.8	5.2	8.0	8.3	7.0		0.0	1		7	02	6
5	12.0	10.5	11.9	6.0	5.9	8.3	8.5	0.5		0.2	2		7	02	6
6	3.1	1.8	6.8	1.2	-3.0	7.5	8.4	Tr		6.5	1		2	01	6
7	4.5	3.7	7.7	0.9	-1.9	6.5	8.4	6.0		0.0	1		6	03	6
8	6.7	6.5	9.5	4.3	-0.6	6.3	8.4	5.7		0.0	2		8	65	3
9	4.3	3.2	7.3	3.9	2.0	6.8	8.4	Tr		5.8	2		5	01	6
10	1.8	1.1	5.1	0.7	-4.5	6.2	8.3	2.2		1.5	4		2	01	6
11	5.0	4.6	8.5	1.5	-1.2	5.7	8.1	0.3		1.2	2		8	63	5
12	1.1	0.8	5.5	0.3	-4.7	5.5	8.0	3.8		2.8	4		2	01	5
13	5.5	5.3	5.8	1.0	-1.3	5.1	8.0	Tr		1.0	2		8	03	4
14	-0.8	-1.2	5.0	-2.4	-7.4	5.2	7.8	6.0		5.9	4		1	01	6
15	3.4	3.1	8.1	-1.5	-7.2	4.2	7.6	1.1		2.3	4		8	63	5
16	3.0	1.6	6.0	1.4	-4.2	4.2	7.6	0.2		3.6	4		3	01	6
17	5.3	4.0	8.5	2.7	-0.5	4.2	7.5			1.0	2		3	02	6
18	4.0	3.3	5.2	3.5	0.4	4.5	7.3	0.2		1.5	1		3	02	6
19	2.3	1.1	5.0	0.3	-3.2	4.3	7.1	0.6		2.8		1	4	02	6
20	3.3	2.5	5.1	1.9	-1.9	4.0	7.0	5.7		4.1	1		2	01	6
21	4.4	4.0	4.7	1.0	-3.1	3.6	7.0	8.9		2.0	2		6	62	6
22	1.0	0.6	2.6	0.2	-2.5	3.5	7.0		2	2.8		3	6	70	6
23	2.5	1.8	4.3	0.1	-3.6	3.5	7.0		2	0.9		3	7	03	6
24	2.3	1.8	9.5	0.4	-4.0	3.4	6.6	0.2		0.0		2	6	02	5
25	6.9	5.2	6.8	1.4	0.4	3.9	6.4	0.1		0.0	2		5	02	6
26	3.2	2.0	5.2	1.8	-4.1	4.0	6.4	0.1		1.6	1		2	01	6
27	4.2	3.2	9.2	1.4	-2.5	3.6	6.4	Tr		0.0	1		5	03	6
28	9.2	7.6	12.6	4.0	1.8	4.0	6.3	1.2		1.3	1		6	02	7
29	8.1	8.0	8.6	7.8	7.0	5.0	6.3	18.9		0.0	2		8	61	4
30	5.0	4.9	9.0	3.0	2.8	5.0	6.2	2.7		0.0	2		8	61	4
31	4.4	4.0	4.9	4.0	2.5	5.0	6.2	2.2		0.0	1		6	01	6
MONTH	5.0	4.2	7.8	2.4	-0.8	5.3	7.5	74.2		52.6			5.2		
AVERAGE			6.4	1.0				61.5		41.85					

Monthly Rainfall	% of Average	Monthly Sunshine	% of Average	% of Possible
74.2 mm	121%	52.6	126%	23%

DATE	Direction tens of degrees	Speed in knots	WEATHER
1	25	20	Cloudy. Strong SW winds
2	20	11	Cloudy, showers
3	25	20	Cloudy, strong winds and showers
4	24	07	Cloudy, rain. Strong wind at night
5	25	18	Cloudy, strong SW winds continuing, rain at night
6	27	05	Ground frost, bright and sunny, rain at night
7	19	15	Ground frost, cloudy, rain late afternoon
8	C A L M		Ground frost, cloudy, rain, heavy at times
9	30	10	Cloudy, becoming brighter, sunny intervals
10	23	03	Ground frost, bright sunny intervals, rain at night
11	21	13	Rain, ground frost, SW wind, becoming brighter late afternoon
12	22	04	Ground frost, bright sunny intervals, rain at night
13	22	02	Frost, cloudy, cold, becoming brighter, sunny intervals, rain at night
14	23	01	Frost, cold day, becoming brighter with sunny intervals, " " "
15	21	15	Frost, rain, cold day, becoming brighter with sunny intervals
16	29	09	Frost, bright and sunny intervals
17	29	07	Cloudy, becoming brighter, ground frost, sunny intervals
18	26	10	Bright, sunny intervals, cold day
19	30	09	Slight snowfall, ground frost, becoming brighter
20	21	20	Ground frost, bright and sunny, rain at night
21	04	18	Ground frost, becoming brighter, rain at night, sleet & snow shwrs.
22	35	09	Snow showers, ground frost, becoming brighter with sunny intervals
23	34	08	Cloudy, ground frost
24	17	04	Cloudy, ground frost
25	04	08	Cloudy, slight rain
26	25	06	Bright, ground frost, sunny intervals
27	28	12	Cloudy, ground frost, west wind
28	28	12	Cloudy, west wind, sunny intervals
29	33	06	Light rain, cloudy, rain all day. Relatively mild
30	12	05	Overnight rain. Cloudy, rain until afternoon
31	32	05	Cloudy day with rain at times
MEAN		9.4 knots	
AVERAGE		9.1 knots	

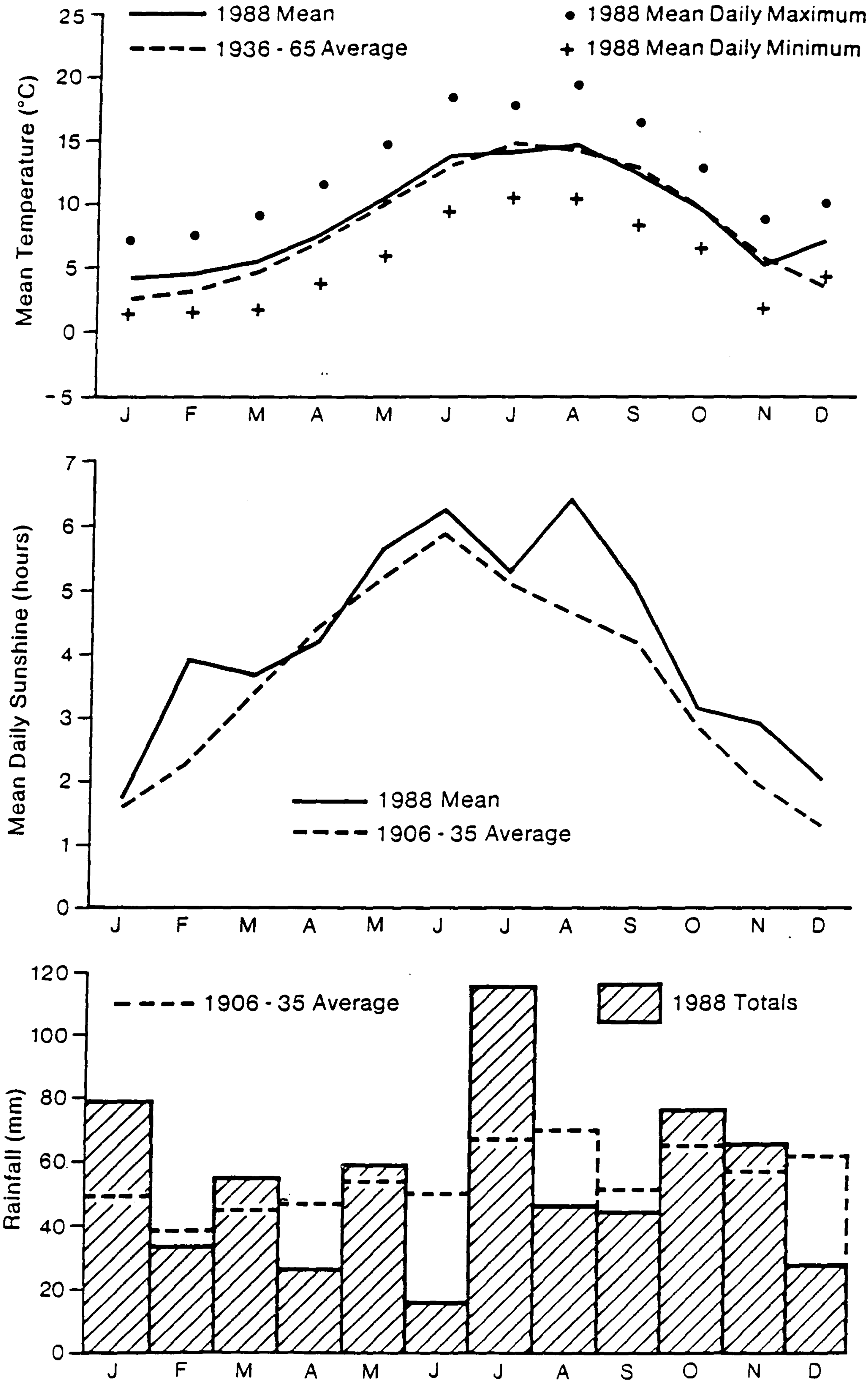
Summary Of
Meteorological Observations
1987

MEAN TEMPERATURES, SUNSHINE AND RAINFALL AT DURHAM, 1987



Summary Of Meteorological Observations 1988

MEAN TEMPERATURES, SUNSHINE AND RAINFALL AT DURHAM, 1988



APPENDIX B

I. The Growth Stages of Cereals

II. The Growth Stages of Oilseed Rape

III. The Growth Stages of Potatoes

Sources

A D A S (1984)

F A O (1973)

The Growth Stages of Cereals

Table 1 The descriptions of the principal and secondary growth stages of the Zadoks decimal code for cereals

0 Germination
00 Dry seed
01 Start of imbibition (water absorption)
02 ---
03 Imbibition complete
04 ---
05 Radicle (root) emerged from caryopsis (seed)
06 ---
07 Coleoptile
08 ---
09 Leaf just at coleoptile tip

1 Seedling growth
10 First leaf through coleoptile
11 First leaf unfolded
12 2 leaves unfolded
13 3 leaves unfolded
14 4 leaves unfolded
15 5 leaves unfolded
16 6 leaves unfolded
17 7 leaves unfolded
18 8 leaves unfolded
19 9 or more leaves unfolded

2 Tillering
20 Main shoot only
21 Main shoot and 1 tiller
22 Main shoot and 2 tillers
23 Main shoot and 3 tillers
24 Main shoot and 4 tillers
25 Main shoot and 5 tillers
26 Main shoot and 6 tillers
27 Main shoot and 7 tillers
28 Main shoot and 8 tillers
29 Main shoot and 9 or more tillers

3 Stem elongation
30 Pseudostem (leaf sheath) erection
31 First node detectable
32 2nd node detectable
33 3rd node detectable
34 4th node detectable
35 5th node detectable
36 6th node detectable
37 Flag leaf just visible
38 ---
39 Flag leaf ligule just visible

4 Booting
40 ---
41 Flag leaf sheath extending
42 ---
43 Boots just visibly swollen
44 ---
45 Boots swollen
46 ---
47 Flag leaf sheath opening
48 ---
49 First awns visible

5 Inflorescence (ear/panicle) emergence
50 ---
51 First spikelet of inflorescence just visible
52 ---
53 1/4 of inflorescence emerged
54 ---
55 1/2 of inflorescence emerged
56 ---
57 3/4 of inflorescence emerged
58 ---
59 Emergence of inflorescence

6 Anthesis (flowering)
60 ---
61 Beginning of anthesis
62 ---
63 ---
64 ---
65 Anthesis half-way
66 ---
67 ---
68 ---
69 Anthesis complete

7 Milk development
70 ---
71 Caryopsis (kernel) water ripe
72 ---
73 Early milk
74 ---
75 Medium milk
76 ---
77 Late milk
78 ---
79 ---

8 Dough development
80 ---
81 ---
82 ---
83 Early dough
84 ---
85 Soft dough
86 ---
87 Hard dough
88 ---
89 ---

9 Ripening
90 ---
91 Caryopsis hard (difficult to divide)
92 Caryopsis hard (not dented by thumbnail)
93 Caryopsis loosening in daytime
94 Over-ripe, straw dead and collapsing
95 Seed dormant
96 Viable seed giving 50% germination
97 Seed not dormant
98 Secondary dormancy induced
99 Secondary dormancy lost

Fig 1 Cereals: Germination

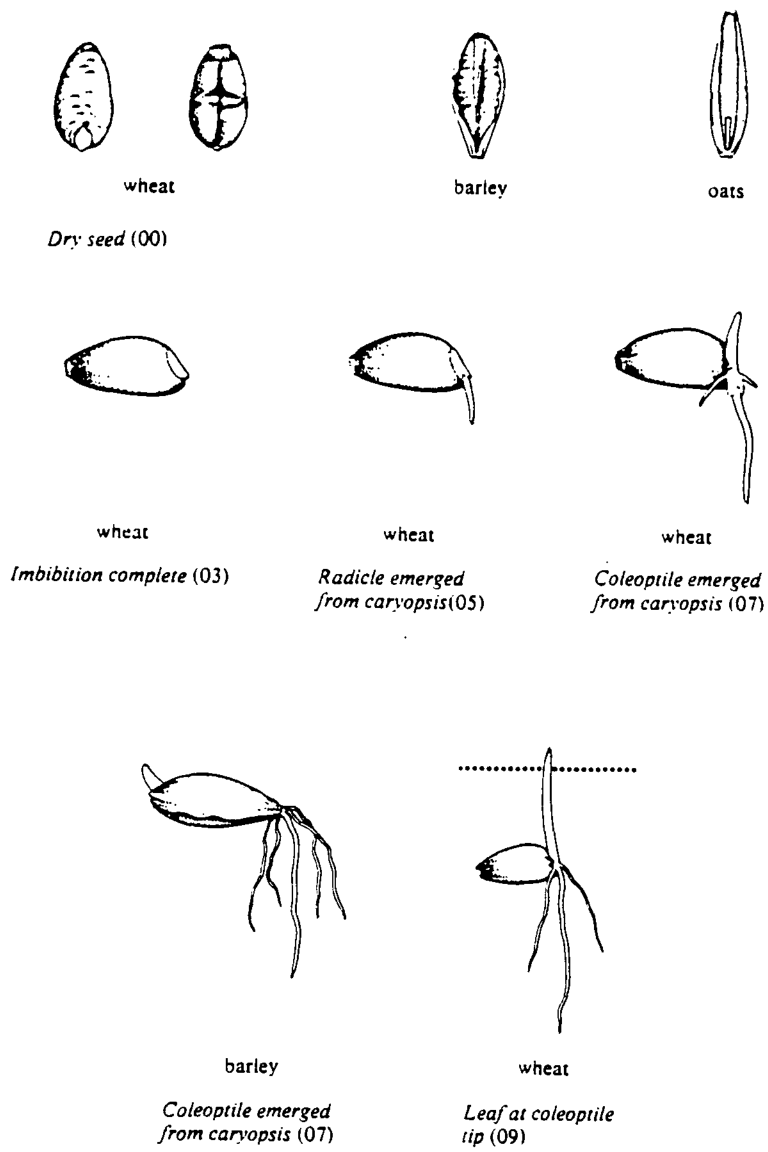


Fig 2 Cereals: Leaf and Tiller production

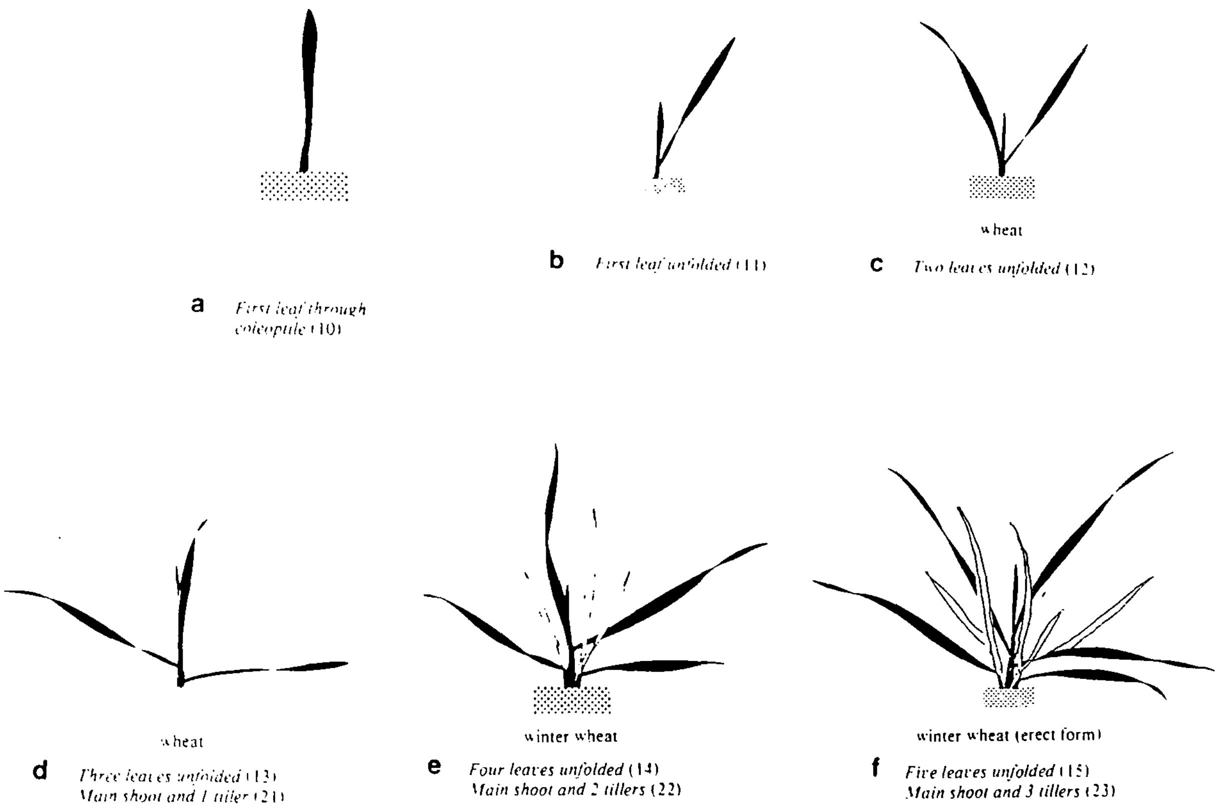
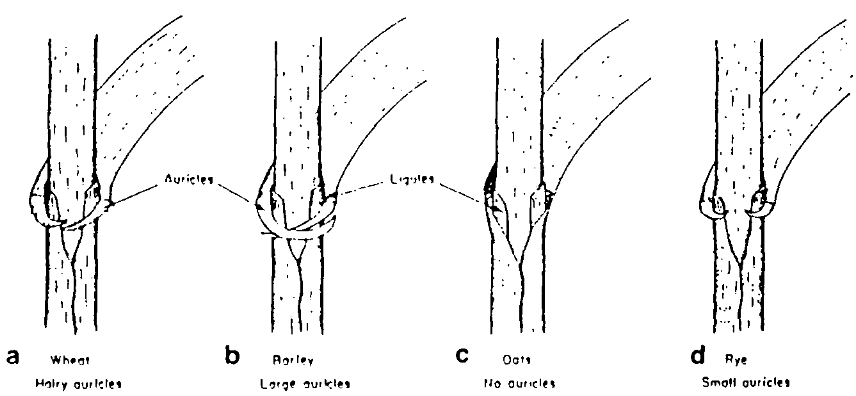


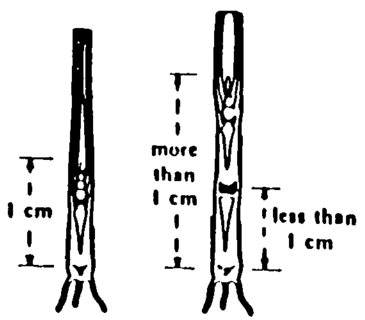
Fig 3 Cereals: Assessing leaf emergence (ligule/auricles)



Diagrams showing method of recognizing cereals in the leafy (vegetative) stage

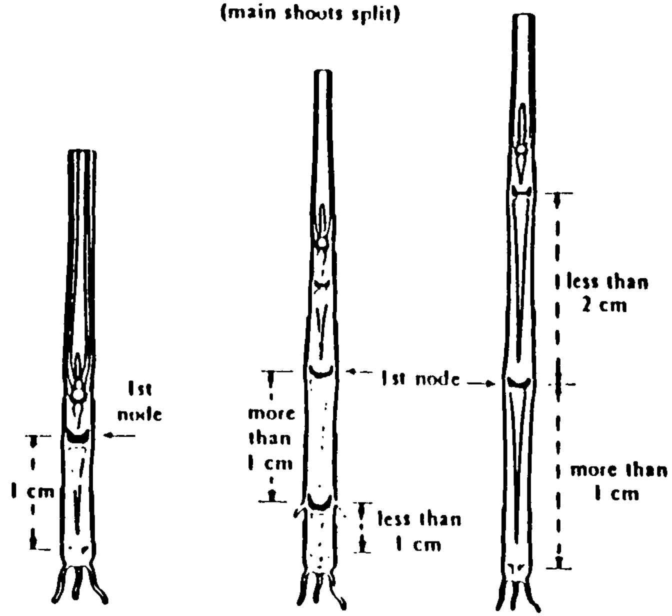
Fig 4 Cereals: Stem elongation

a *Ear at 1 cm* (30)
(main shoots split)



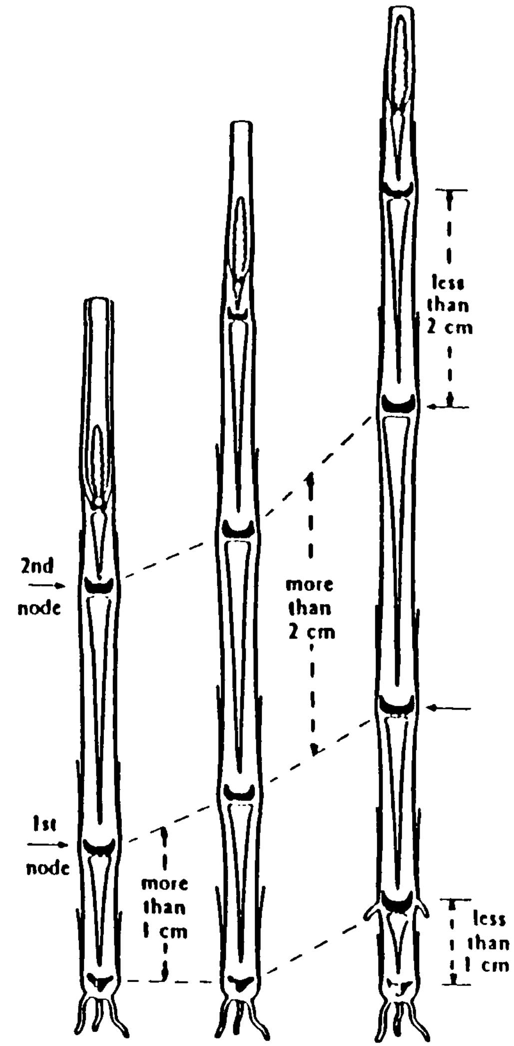
The stem, from where the lowest leaves are attached, is 1 cm or more to the shoot apex.

b *First node detectable* (31)
(main shoots split)



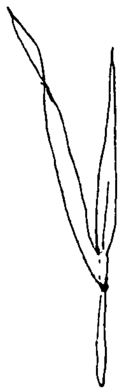
An internode of 1 cm or more is present but the internode above it is less than 2 cm.

c *Second node detectable* (32)
(main shoots split)



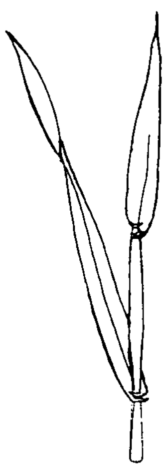
Second and subsequent nodes are counted when the internode below them exceeds 2 cm.

Fig 5 Cereals: stem elongation and booting



wheat

a *Flag leaf ligule just visible* (39)

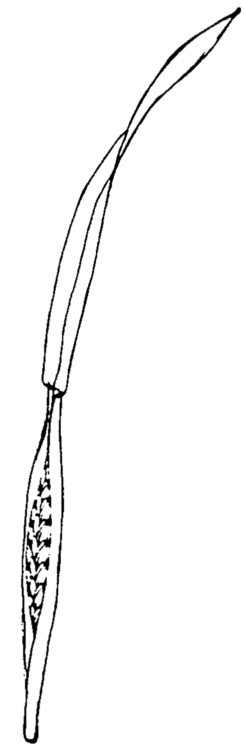


barley

b *Flag leaf sheath extending* (41)

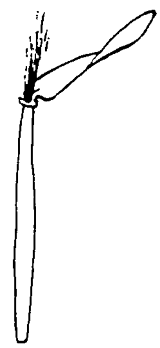
wheat

c *Boots swollen* (45)
Fourth node detectable (34)
Main shoot and 4 tillers (24)
(*2 infertile*)



wheat

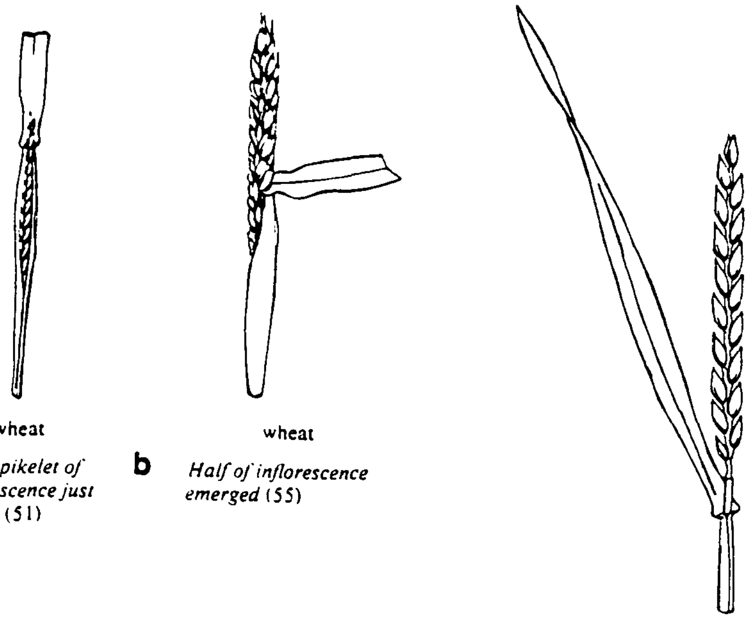
d *Flag leaf sheath opening* (47)



barley

e *First awns visible* (49)

Fig 6 Cereals: Ear emergence



wheat

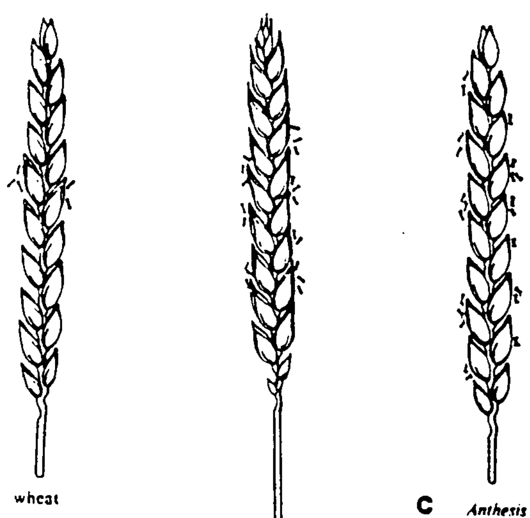
a *First spikelet of inflorescence just visible* (51)

wheat

b *Half of inflorescence emerged* (55)

c *Emergence of inflorescence completed* (59)

Fig 7 Cereals: Flowering



wheat

a *Beginning of anthesis* (61)

b *Anthesis half-way* (65)

c *Anthesis complete* (69)

Fig 8 Cereals: Milk development

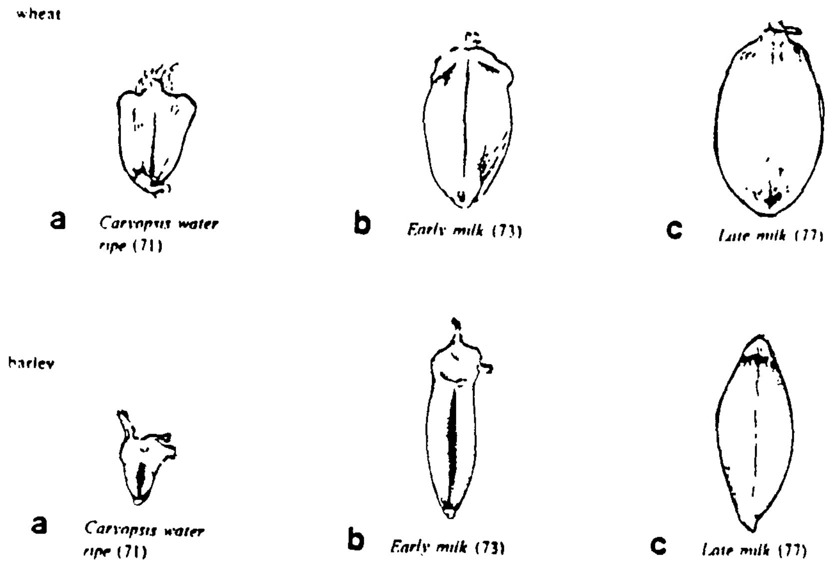
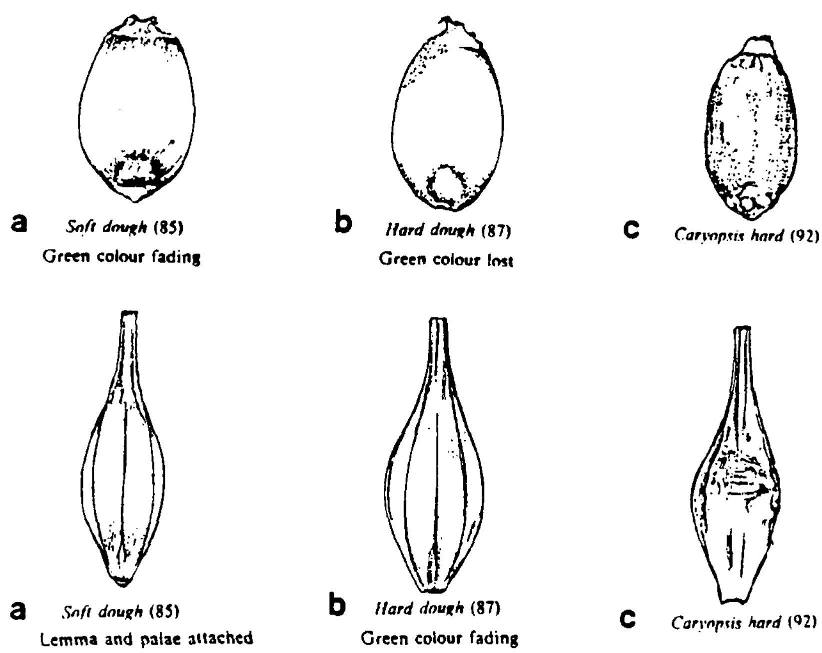


Fig 9 Cereals: Dough development



The Growth Stages of Oilseed Rape

Table 2 The descriptions of the principal and secondary growth stages of the decimal code for oilseed rape

Code	Definition
0 Germination and emergence	
0,0	Dry seed
0,2	Imbibed seed
0,4	Radicle emerged
0,6	Hypocotyl emerged
0,8	Cotyledons emerged
1 Leaf Production	
1,0	Both cotyledons unfolded and green
1,1	First true leaf exposed
1,2	Second true leaf exposed
1,3	Third true leaf exposed
1,4	Fourth true leaf exposed
1,5	Fifth true leaf exposed
:	:
1,10	About tenth true leaf exposed
:	:
1,15	About fifteenth true leaf exposed
2 Stem Extension	
2,0	No internodes detectable ("rosette")
2,1	One internode detectable
2,2	Two internodes detectable
2,3	Three internodes dectectable
etc	
2,10	Ten internodes detectable

Note - the following descriptions should normally be applied to the raceme on the main stem (ie the terminal branch)

Code	Definition
3 Flower Bud Development	
3,0	Only leaf buds present
3,1	Flower buds present but enclosed by leaves
3,3	Flower buds visible from above ("green bud")
3,4	Flower buds level with leaves
3,5	Flower buds raised above leaves
3,6	First flower stalks extending
3,7	First flower buds yellow ("yellow bud")

Code	Definition

4 Flowering

4,0	First flower opened
4,1	10% all buds opened
4,2	20% all buds opened
4,3	30% all buds opened
etc	
4,9	All viable buds on raceme opened

5 Pod Development

5,0	Lowest pods more than 2 cm long
5,1	10% potential pods more than 2 cm long
5,2	20% potential pods more than 2 cm long
5,3	30% potential pods more than 2 cm long
etc	
5,9	All potential pods more than 2 cm long

Note - the following should normally be applied to the lowest third of the raceme on the main stem.

6 Seed Development

6,1	Seed expanding
6,2	Most seeds translucent but full size
6,3	Most seeds green
6,4	Most seeds green-brown mottled
6,5	Most seeds brown
6,6	Most seeds dark brown
6,7	Most seeds black but soft
6,8	Most seeds black and hard
6,9	All seeds black and hard

7 Leaf Senescence

No subdivisions identified for this growth stage.

8 Stem Senescence

8,1	Most of stem green
8,5	Half of stem green
8,9	Little of stem green

9 Pod Senescence

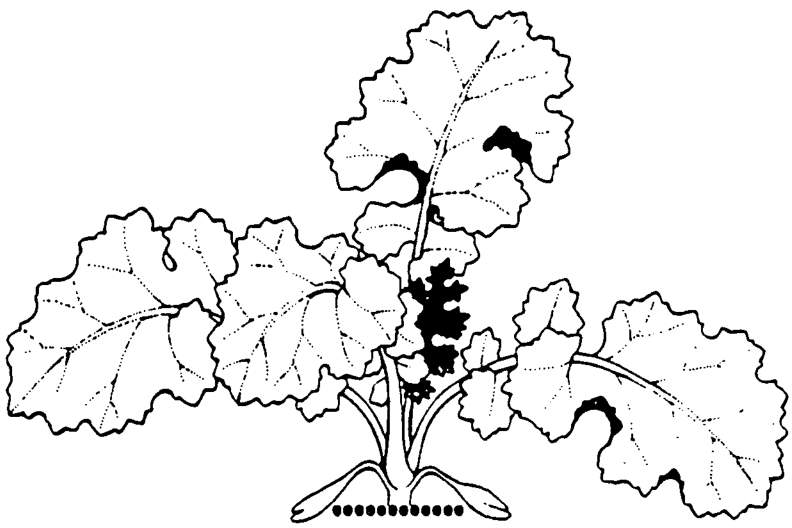
9,1	Most pods on main stem raceme green (lowest third)
9,5	Half pods on main stem raceme green
9,9	Few pods on main stem raceme green

Fig 10 Oilseed rape: Germination and Leaf emergence

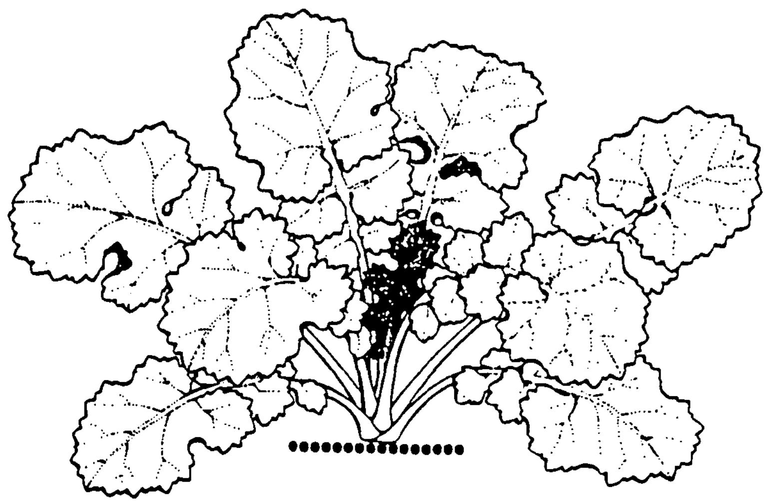
a *Cotyledons emerged (0.8).*

b *Both cotyledons unfolded and green (1.00). First true leaf unexposed.*

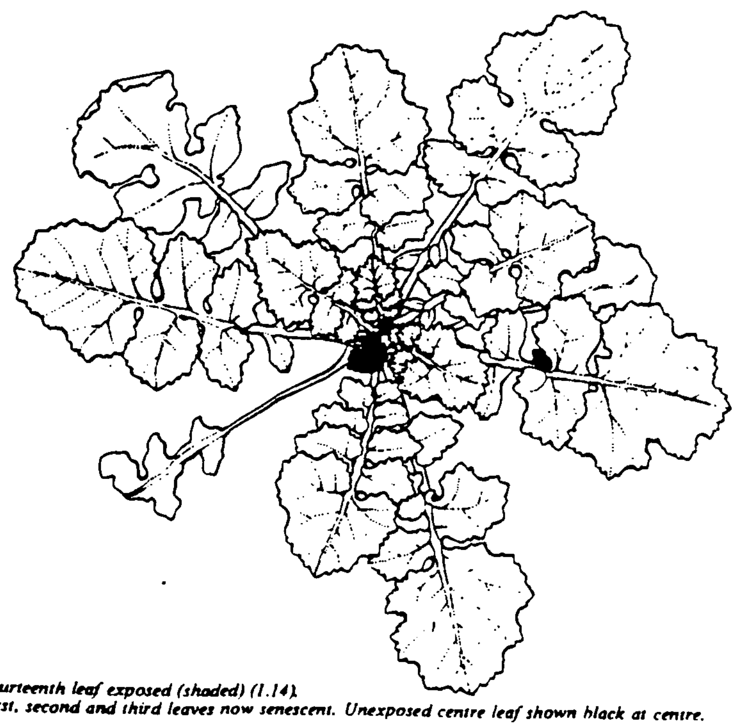
Fig 11 Oilseed rape: Leaf emergence



a *Fifth true leaf exposed (1.05). Cotyledons moribund.*

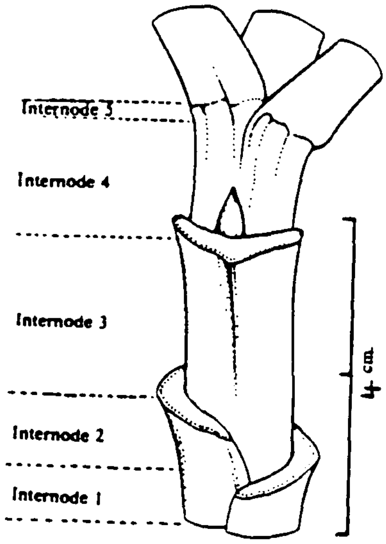


b *Ninth true leaf exposed (1.09).*

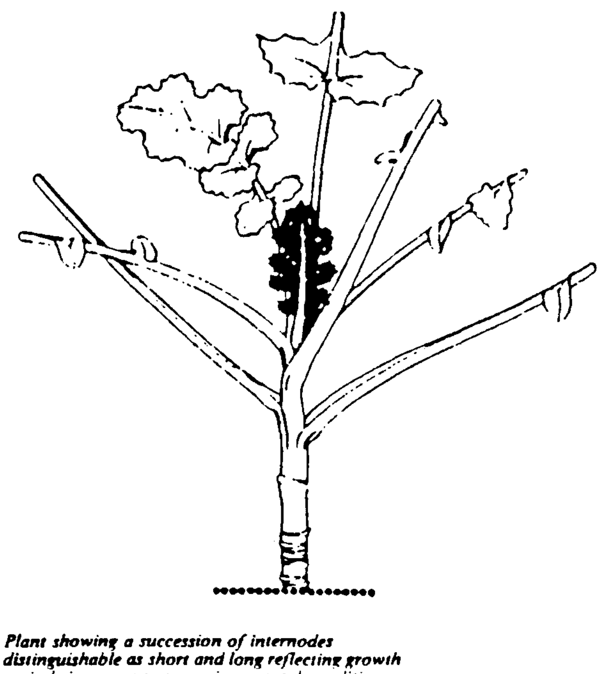


c *Fourteenth leaf exposed (shaded) (1.14).*
First, second and third leaves now senescent. Unexposed centre leaf shown black at centre.

Fig 12 Oilseed rape: Stem elongation

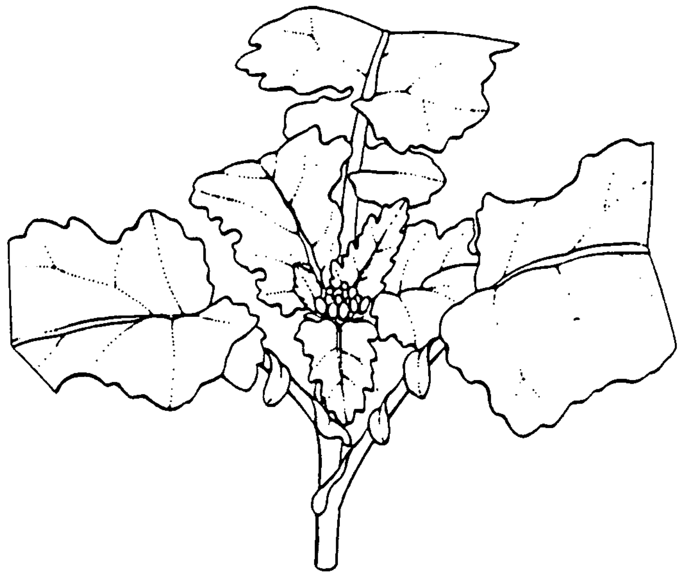


a *Two internodes detectable (2.02). Internodes 1 and 2 are shortened early autumn internodes. Internodes 3 and 4 are partially extended from autumn growth. Internode 5 has yet to extend.*



b *Plant showing a succession of internodes distinguishable as short and long reflecting growth periods in response to environmental conditions.*

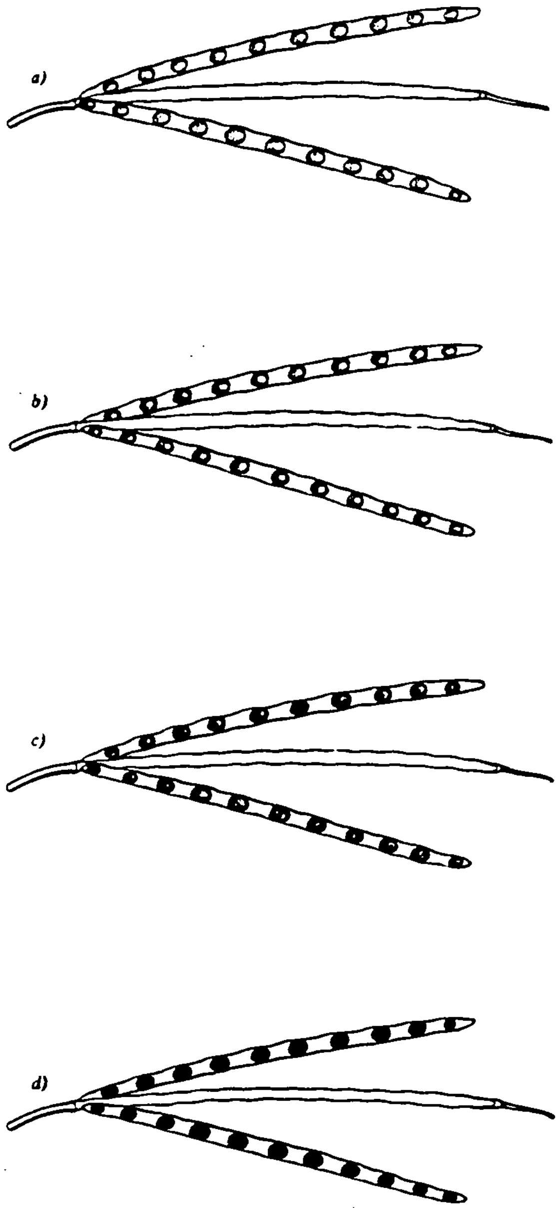
Fig 13 Oilseed rape: Flower bud development



a *Flower buds visible from above - green bud (3.3).*

b *First flowers opened (4.1).*
Older bud yellow tipped. Flower stalks extended giving inflorescence a flattened form.

Fig 15 Oilseed rape: Seed development

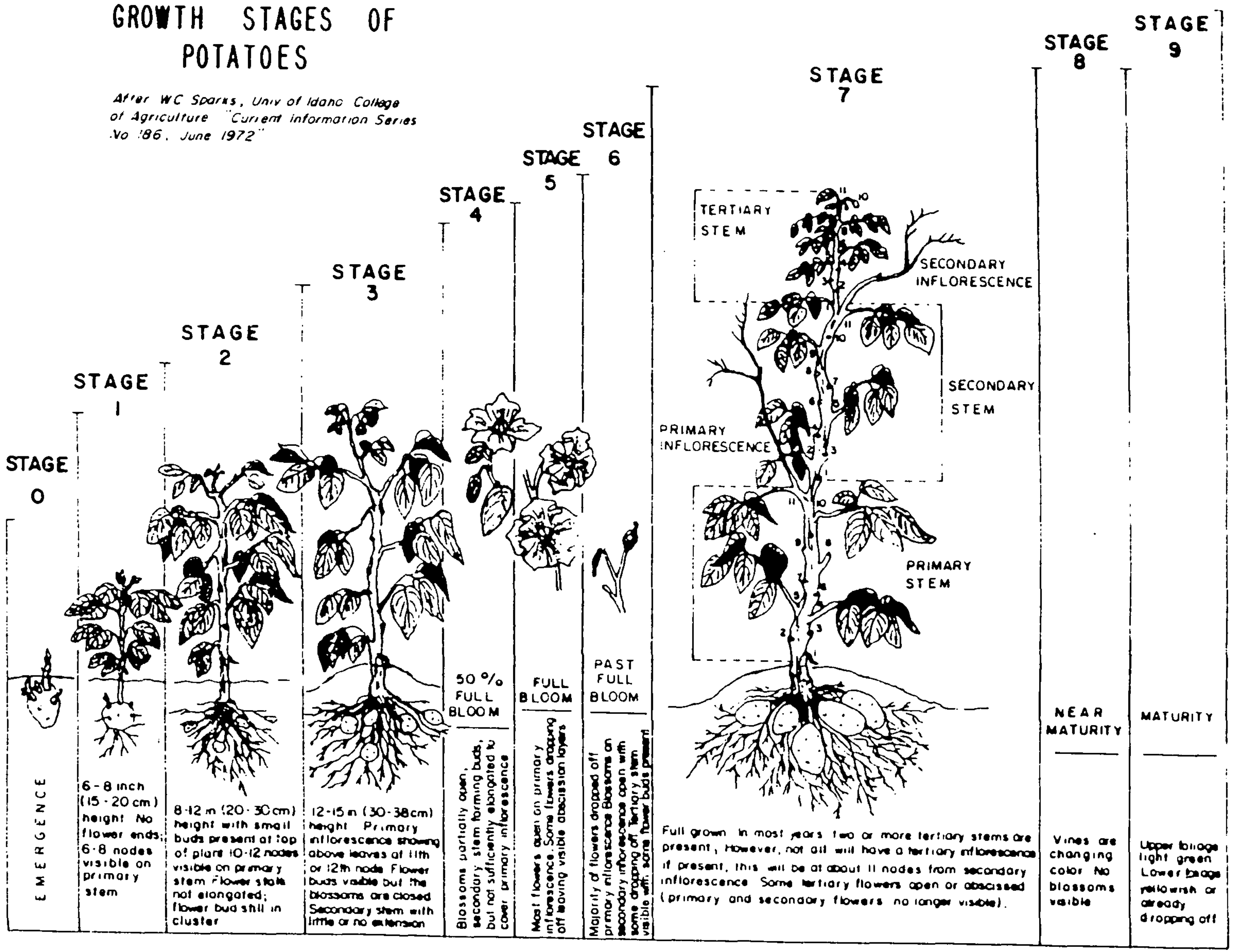


Seed development. Stages of ripening of the seed when desiccation is likely to occur.
a) Most seeds green-brown mottled (6.4) b) Most seeds brown (6.5) c) Most seeds dark brown (6.6)
d) Most seeds black (6.7-6.8).

Fig 14 Oilseed rape: Flowering and Pod development

a *20% all buds on raceme flowering or flowered (4.2). Axillary raceme with flower stalks extending (3.6).*

b *70% all buds on raceme flowering or flowered. 20% potential pods on raceme more than 2 cm long (4.7 5.2).*


GROWTH STAGES OF POTATOES
After WC Sparks, Univ of Idaho College of Agriculture "Current information Series No 186, June 1972"
STAGE 0
EMERGENCE
STAGE 1
6 - 8 inch (15 - 20 cm) height No flower ends; 6-8 nodes visible on primary stem
STAGE 2
8-12 in (20 - 30 cm) height with small buds present at top of plant 10-12 nodes visible on primary stem Flower stalk not elongated; flower bud still in cluster
STAGE 3
12-15 in (30-38cm) height Primary inflorescence showing above leaves at 11th or 12th node Flower buds visible but the blossoms are closed Secondary stem with little or no extension
STAGE 4
50 % FULL BLOOM
Blossoms partially open, secondary stem forming buds, but not sufficiently elongated to cover primary inflorescence
STAGE 5
FULL BLOOM
Most flowers open on primary inflorescence. Some flowers dropping off leaving visible abscission layers
STAGE 6
PAST FULL BLOOM
Majority of flowers dropped off primary inflorescence Blossoms on secondary inflorescence open with some dropping off Tertiary stem visible with some flower buds present
STAGE 7
TERTIARY STEM
SECONDARY INFLORESCENCE
SECONDARY STEM
PRIMARY INFLORESCENCE
PRIMARY STEM
Full grown In most years two or more tertiary stems are present, However, not all will have a tertiary inflorescence if present, this will be at about 11 nodes from secondary inflorescence Some tertiary flowers open or abscissed (primary and secondary flowers no longer visible).
STAGE 8
NEAR MATURITY
Vines are changing color No blossoms visible
STAGE 9
MATURITY
Upper foliage light green Lower foliage yellowish or already dropping off