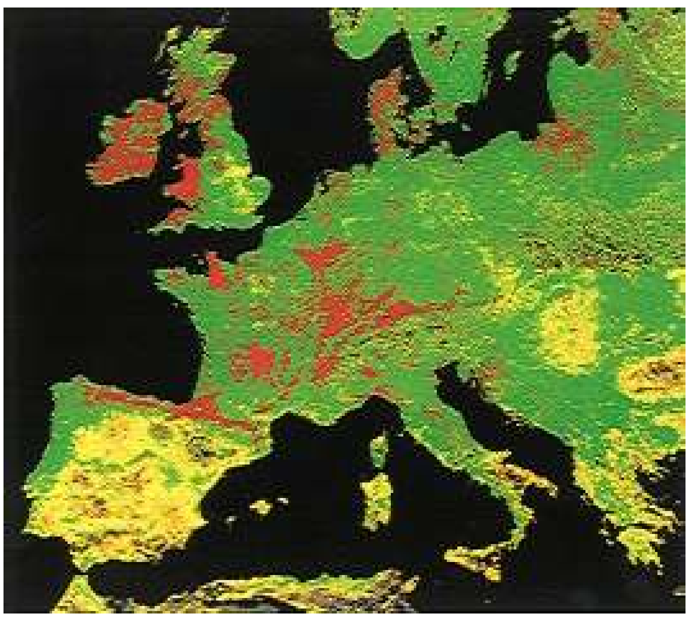
AN AGRICULTURAL INFORMATION SYSTEM FOR THE EUROPEAN COMMUNITY

Agriculture

BARLEY KNOWLEDGE BASE

by
G. Russell



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1990

Cover photograph - Maximum value composite of the Normalised Difference Vegetation Index (NDVI) for July 1989. This product is part of a time series of similar data which will be used by the Agriculture Project for the zoning of agricultural regions of the European Community.
(Data processed by the Agriculture Project)

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by
G. Russell
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Financed by the
Pilot Project for Remote Sensing Applied to Agricultural Statistics
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CONTENTS

General Preface

Precise and up-to-date information on agricultural production is a vital component in running market economies. Such data are even more important where, as in the European Community, a common agricultural policy is one of the important aims. Such a policy relies on certain levels of precision of agricultural statistics but these are not always adequate for its users. This is mainly due to the fact that, despite the progress which has already been made by the Statistical Office of the European Community (O.S.C.E) in integrating Community statistics, national systems of agricultural statistics still differ in their approach to conventional surveys and the resouces available.

Remote sensing seems to be the most promising technique for upgrading the agricultural statistics system. To obtain rapid improvements, while avoiding duplication of work and a diversity of methods, the Commission has set up a Pilot Project to introduce remote sensing into the European Community agricultural statistics system. The Joint Research Centre is in charge of this project, the objectives being defined according to the priorities of Directorate General VI - Agriculture.

The first requirement is to distinguish, identify and measure the area of important crops. The second is to estimate production in good time so that decisions can be made. When these basic statistics are available, predictions of crop production can then be made.

It is intended that the results of this project will form part of the "Advanced System of Information on Agriculture". This system will depend on new sources of information such as remote sensing data from high and low resolution instruments and on methods of interpretation such as agrometeorological models. But although the emphasis has been placed on remote sensing in the Pilot project, in an operational system these techniques will complement conventional surveys.

The programme has been structured into 7 actions on the basis of priorities, methods and types of satellite data required (See the Table below). Actions 1-5 each correspond to a given operational objective. Action 6 supports all the actions. Action 7 consists of several long-term research items, unconnected with any particular operational objective.

For each action, a specific methodology has been developed. Research is currently (1990) being undertaken in support of the semi-operational objective (actions 1, 2, 3 and 4).

In Action 3 (Yield forecasting models), the objectives are to develop agrometeorological models for regional monitoring of crop state and for quantitative yield predictions on a national scale. The models that eventually will be applied may be newly developed ones or adaptations of current models. As is implicit in the double objective, the applications

OUTLINE OF THE AGRICULTURE PROJECT

Action	Method	Geographic localization	Input
1. Regional inventories (area)	Regression between ground observations and data from space	5 selected administrative regions	High resolution satellite data (SPOT, LANDSAT-TM)
2. Vegetation conditions and yield indicators	Spatial or temporal comparison of V.I. and T_s integrated indices,...)	Selected regions and sampling sites; then all of Europe.	Low resoltuion satellite data (mainly AVHRR).
3. Models of yield prediction	- improvement of existing agrometeo-rological models - integration of satellite data and agromet, models - derivation of agronomic parameters (AET) - direct relationships		Meteorological data Low resolution satellite data High resolution satellite data
4. Rapid estimates of European crop areas and potential yield	Computer assisted photo-interpretation	Sampling of some 50 sites throughout Europe	High resolution satellite data
Support actions			
5. Advanced Agriculture Information System	Comparision with previous years		Integration of all available results
6. Area frame sampling and associated surveys	Integration of the preceding methods with conventional ones		Thematic maps; sample-surveys with farmers;
7. Long term research	Support documents or data for other actions		New sensors' data; GIS - expert systems;

must be implemented on a small scale, meaning that agrometeorological monitoring of crop state and growing conditions refer to rather large areas of, say, several thousands of square kilometres. It is not intended to produce large scale outputs at the scale of villages or small regions. Also, quantitative yield forecasts or estimates are only intended to be made for countries as a whole or possibly for very large autonomous regions within the larger countries of the European Community.

Several activities are being implemented in order to realise the objectives of Action 3, and to solve some of the specific problems related to the use of small scale agrometeorological modelling. The most important activities are briefly described below.

1. Agrometeorological crop inventories

   An enormous amount of research into the relationships between crop growth and development, crop yield and weather conditions has been carried out. However, very few studies have attempted to summarize and organise these research results into inventories that provide information on these relationships at a regional scale. Nor are there regional studies for many crops of typical current agricultural practices and the agro-technological trends over the past 20 years or so.

   Within the framework of the Pilot Project, inventories are being prepared for barley, maize and potato in the EC, for the major food crops of the BENELUX, for the major food crops of Ireland and the United Kingdom, for the major crops of Italy, Greece and Spain and for vines in France.

2. Potential evapotranspiration (PET)

   A similar situation to the preceding one occurs for the estimation of the agro-climatological concept of potential evapotranspiration (PET): almost each University and agronomic or hydrologic research institute has developed, chosen or validated its own formula or method for the estimation of PET. The regional validity of these formulae is often quite limited and up until now, no attempt has been made to harmonize the methods used to calculate PET for the European Community. As PET is a key input in many agrometeorological models, a study is presently being carried out to propose a single method for the calculation of PET, which will give reliable estimates of ten-day PET-totals and which will be valid for all of the EC-regions, possibly after regional adjustment according to climate.

3. Maximum available water capacity (AWC) of the soils of the European Community

   Another key variable in agrometeorological crop modelling, is the Maximum Available Water Capacity of a soil. Since no ready-to-use information or maps were available for the EC, the French Institut National de Récherche Agronomique (INRA), has prepared a 1:1,000,000 AWC map of the EC soils on behalf of the Pilot Project. The data were derived from the 1:1,000,000 EC soil map, using specially developed pedotransfer functions.

4. Spatialization of meteorological input data

The European meteorological network is relatively sparse considering the large range of reliefs and elevations. Consequently, techniques need to be derived to allow accurate interpolation of data from the existing network of meteorological stations taking account of topographical variability. Part of the Pilot Project's activities consists therefore of the evaluation and development of such methods, accurate for ten-day periods and with a spatial resolution of *approximately* 50 x 50 km.

5. Agrometeorological modelling

The ultimate use of all the preceding information is to serve as reliable input data in agrometeorological models for crop state monitoring and yield forecasting. In theory, there exists a large choice of models, ranging from purely statistical approaches, to highly sophisticated mechanistic crop simulation models with many input variables. However, in practice it appears that very few models have proven trustworthy when applied on a regional scale when only a limited number input parameters are available. A major activity is thus the identification and adaptation of existing models and possibly the development and validation of new models. Figure A below schematically shows how the agrometeoroligical inventories could be used in a possible model. However, it must be emphasised that no existing model type or other approach for crop monitoring and yield forecasting has been excluded *a priori*: the Pilot Project is also supporting the testing of the "*pollen in the atmosphere*" technique for the prediction of wine and olive production in the Mediterranean countries. On behalf of the Pilot Project, the Belgian State Faculty for Agricultural Sciences in Gembloux, is updating the existing *EUROSTAT/ AGROMET* statistical model so as to include the prediction of national fruit, grape and olive production.

6. Interfacing remote sensing and agrometeorological modelling

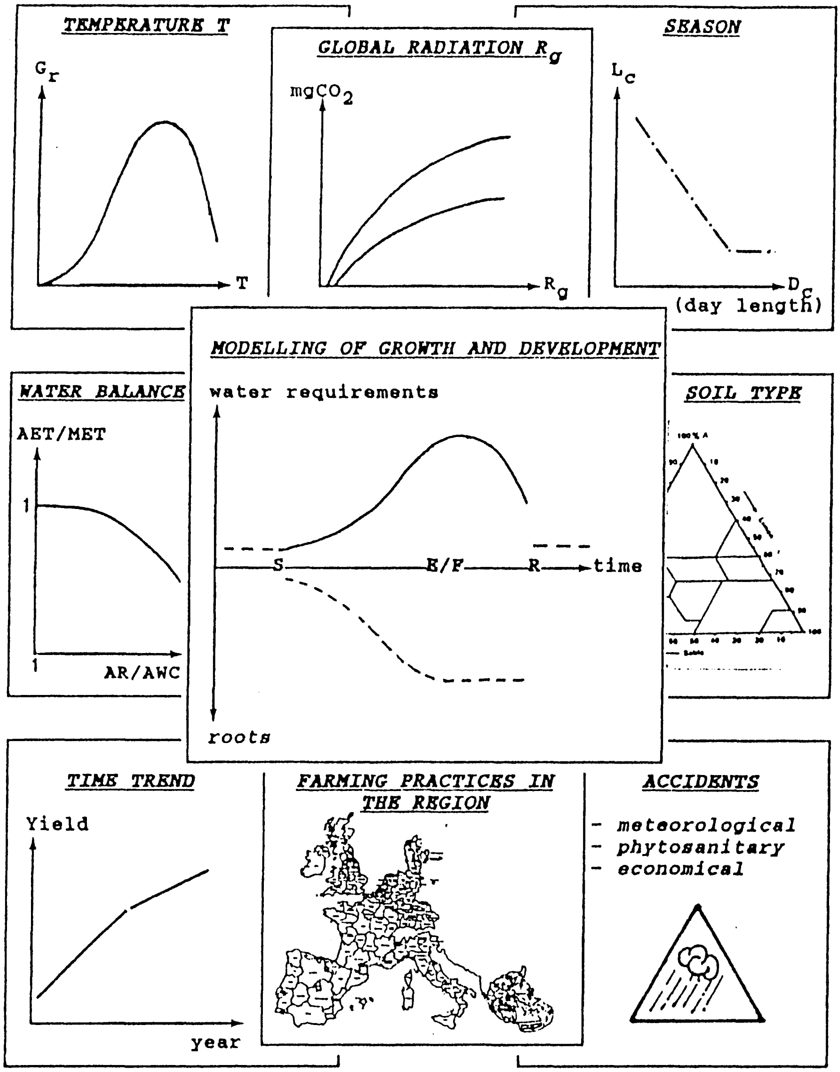
The introduction of remotely sensed information into the models is likely to significantly improve the spatial representativity and the trustworthiness of both the model inputs and outputs. Such improvements are expected from an appropriate use of AVHRR information, especially for the following purposes:

a. the spatialisation of inputs such as meteorological data and of certain ouputs such as, for example, drought severity indicators;

b. the creation of a 1:1,000,000 land cover map of the EC;

c. an improved fitting of crop cycle lengths and major phenological stages (eg flowering) in the agricultural season; possible *a posteriori* adjustments of model-based assumptions of, for example, flowering and harvest period;

FIGURE A: EXAMPLE OF A GENERAL TYPE AGRO-METEOROLOGICAL MODEL



(With: G_r = growth rate; L_c = cycle length; **S** = sowing; **E/F** = earing/flowering; **R** = maturity; **AET, MET** = actual and maximum evapotranspiration; **AR** = actual soil moisture reserve; **AWC** = Available Water Capacity).

d. an improved, more reliable and spatially correct depiction of alarm situations such as droughts, extreme colds and abnormal high temperatures;

e. the possible direct input of remotely sensed data into the agrometeorological models. Although more research still has to be done, it is expected that within a few years remotely sensed surface temperatures and evaporation may be used directly as inputs in models and result in improved and more reliable ouputs.

7. A geographical information system (GIS)

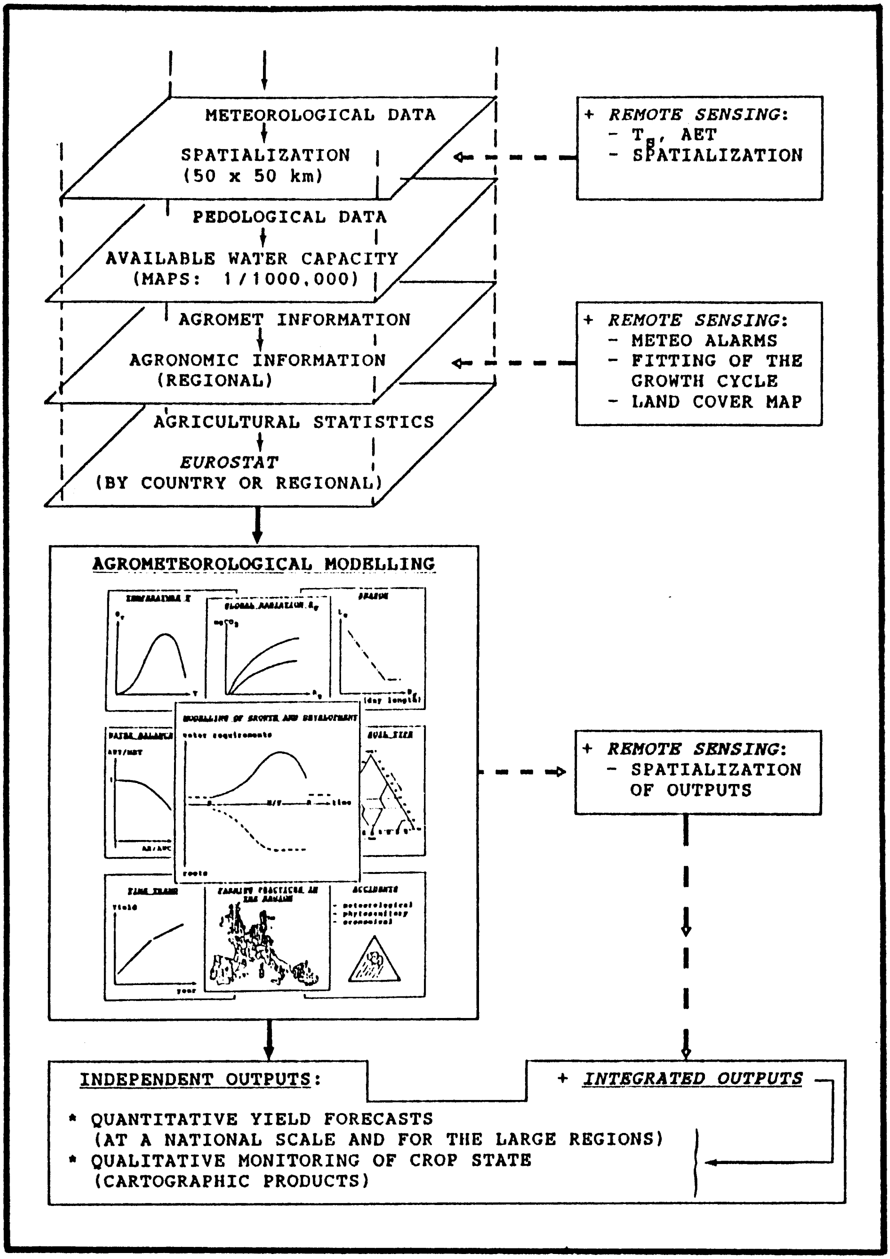
Working on a continental scale, with its diversity of climates, crops, soils, agricultural practices and technologies, requires powerful computer software to overlay, combine and possibly integrate all this data and information. The Pilot Project has therefore installed a Geographic Information System, which will occupy a central position, not only in the implementation of the Action 3 objectives, but also in the integration of all the other Actions of the Project within the Advanced Agricultural Information System. The general design of this System is illustrated below (Fig.B).

The series *'An Agricultural Information System for the European Community'* of the official publications of the European Communities is being used to publish the study results which are considered to have a significant value for the scientific community of the European Communities.

The present *Barley knowledge base* by Dr Graham Russell, is the first to be published. As shown in the Acknowledgements, the book is the result of an intensive exchange of information between many institutes and individuals from each of the EC countries and has therefore contributed to the further integration of Europe.

Jean Meyer-Roux
Manager of the Pilot Project
1 June 1990

FIGURE B: DIAGRAM OF THE ACTIVITIES OF ACTION 3 OF THE PILOT PROJECT



Preface

This volume is an amended version of the final report of Contract No. 3583-88-12 ED ISP GB (An agrometeorological inventory of barley in the European Community) carried out at the University of Edinburgh for the Institute for Remote Sensing Applications of the Joint Research Centre, Ispra in Italy. The work was carried out in accordance with the specifications of the JRC-Ispra with the aim of providing a comprehensive account of the factors affecting barley production in the European Communities. As explained in the General Preface to this volume, the information will be incorporated in an advanced agricultural information system. A knowledge base is an 'explicit structured representation of the underlying rules of some area of human expertise' (Black, 1986) and this volume should be considered as a first attempt to assemble such a corpus of knowledge for barley. Capturing this information in a computer system is rather difficult unless the information is presented in the form of tables, relationships and rules. Three particular objectives were identified at an early stage of the work. The first objective was to develop rules to aid in the interpretation of satellite imagery. In this case the key question is 'given the date and location could this pixel represent barley?' The second objective was to provide a database which could be used as an input to models of yield prediction. To achieve this, the inventory had to be compiled in such a way that it was internally consistent in terms of concepts and definitions and externally compatible with standard meteorological data, a geographic information system holding the 1:1,000,000 soils map of Europe, Eurostat data and information derived from satellite imagery. Since the inputs required could not be specified in detail, the inventory was designed so that it was not model specific but contained information compatible with a wide range of possible inputs. The third objective was to systematise information to be used in the development of crop monitoring systems to warn of the occurrence of meteorological and other types of hazard likely to affect yield.

In the early stages of this project most of the problems were caused by lack of data. Many of these problems were overcome with the help of colleagues throughout Europe although several topics requiring further research were identified. However, it soon became clear that some of the fundamental difficulties were epistemological in nature rather than agronomic and that although this volume would be constrained to represent the current state of knowledge in a conventional manner, any future revisions should ideally be developed from the beginning within an artificial intelligence framework.

Edinburgh, 1990

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Any errors and omissions in this volume are the responsibility of the author and not of the correspondents who provided the data.

Abbreviations and definitions

AET	-	actual evapotranspiration
AWC	-	available water capacity of the soil (see below)
B	-	Belgium
CV	-	cultivar, ie variety
D	-	German Federal Republic
DAS	-	days after sowing
DK	-	Denmark
DMRQ	-	dry matter: radiation quotient (Russell, Jarvis & Monteith, 1989) synonym of light conversion coefficient (g MJ^{-1}) (see section 6.1)
DR	-	double ridge stage of apical development (see section 6.5.3)
DW	-	dry weight
E	-	Spain
EC	-	the European Community of twelve countries
EUR10	-	the EC less Spain and Portugal
F	-	France
FAO	-	Food and Agriculture Organisation of the United Nations
FC	-	field capacity (see below)
GAI	-	green area index (see section 6.5.2)
GR	-	Greece
GS	-	growth stage
I	-	Italy
IRL	-	Republic of Ireland
L	-	Luxembourg
MC	-	moisture content as a percentage of dry weight
MPN	-	maximum primordium number stage of ear development (see section 6.5.4)
NA	-	not applicable
ND	-	not available
NL	-	Netherlands
NUTS	-	Nomenclature des Unités Territoriales Statistiques. This system is employed by Eurostat to describe the division of Europe into administrative regions (Appendix 1)
P	-	Portugal
PAR	-	photosynthetically active radiation (400-700 nm). The flux density of PAR incident on a crop canopy is approximately 50% of the global solar irradiance (Szeicz, 1974)
PET	-	potential evaporation, the sum of evaporation and transpiration from an actively-growing crop well supplied with water
PPD	-	plant population density (plants m^{-2})
RR	-	additional research required
SLA	-	specific leaf area, the ratio of leaf area to leaf dry weight (m^2 kg^{-1})
SWD	-	soil water deficit (see below)
TGW	-	thousand grain weight, that is the weight of 1 000 grains (at 15% MC) after the removal of small and shrivelled grains

UK - United Kingdom
? - information was not found but is probably available

Europe has been divided into regions in various ways. North-west Europe is defined as Belgium, Denmark, Ireland, the Netherlands, the United Kingdom, France (north of latitude 48°N and west of longitude 5°E) and Federal Germany (north of latitude 50°N and west of longitude 10°E). Mediterranean Europe is defined as Greece, Portugal (except Norte), Spain (except Noroeste, Noreste), France (Méditerranée only), Italy (except Nord Ovest, Lombardia, Nord Est). Central Europe comprises the areas not included in either of these lists. Other classifications used have been described in the appropriate place in the text. Yields and production are given at 15% MC unless otherwise stated. Biomass has been defined as the dry weight of a crop per m^2 land surface area. Optimum is used to refer to the range of values of an environmental or other factor within which the rate of a process proceeds at 80% or more of maximum. The term cultivar has been used throughout in preference to variety which is the commercial term.

Day numbers are given on a scale where January 1 is 1 and 31 December is 365 (366 in a leap year). Months are divided into three decades (I, II & III). Thermal time or accumulated temperature is the integral of temperature above a threshold or base temperature with respect to time. A base temperature of 0°C is appropriate for barley and has been used in this volume (see Section 6.1). Thermal time is commonly calculated by subtracting the base temperature from the average of the daily maximum and minimum screen temperatures and then accumulating the resulting figures. Although this method gives an underestimate of the true thermal time whenever the minimum temperature is below the base temperature and the maximum is above, the error involved can often be ignored. This is especially true for spring sowings and in regions where the mean daily temperature is near 0°C for only a few days each growing season. For a daily temperature range of 6°C, which is typical of north-west Europe in winter, the maximum error is 0.75°C d per day and the total error for a three month period must consequently be less than 70°C d. A closer approximation is obtained by using more elaborate formulae such as those developed by the Meteorological Office in the UK (Meteorological Office, 1969).

External development stages have been given according to the decimal system (Zadoks, Chang & Konzak, 1974; Tottman & Makepeace, 1979). The important numerical stages are described as follows: 10 appearance of the first leaf; 21 appearance of the first tiller; 30 onset of stem elongation; 31 first node detectable; 49 first awns visible; 51 start of heading; 65 anthesis half way; 75 medium milk stage of grain development; 85 soft dough stage; 93 harvest ripeness (Fig.1). Apical development terminology (see Section 6.5) follows Kirby & Appleyard (1984). Landes & Porter (1989) have published tables giving conversions between the scales used in this volume and others used elswhere.

FIG. 1 BARLEY DEVELOPMENT STAGES

SEEDLING	TILLERING	STEM ELONGATION	BOOTING	EAR EMERGENCE		RIPENESS	HARVEST
10	21	30	45	49	59	93	

Field capacity is the state of a freely draining soil after excess water has drained following complete wetting of the profile. The soil water deficit is the amount of water (mm) needed to return a soil profile to field capacity. The available water capacity of a soil is the amount of water (mm) available for plant growth. It is taken to be the amount of water held between field capacity and a potential of -1.5 MPa (wilting point) summed over the rooting depth.

Part I

INTRODUCTION

1. Introduction

Barley is the second most important cool temperate cereal in the world after wheat. It is grown from near the equator in Ethiopia to beyond the Arctic Circle at latitude 70°N in Norway, from below sea level in the Netherlands to the limits of cultivation at 5,000 m in Tibet but mainly between latitudes 30 and 60°N. Barley tends to replace wheat where the annual precipitation is too low or too erratic for satisfactory wheat yields. The twelve countries of the European Community grow about two thirds of the barley in Europe (excluding the USSR). Five countries neighbouring the EC, Czechoslovakia, the German Democratic Republic, Morocco, Poland and Turkey are also large producers of barley with a combined production equivalent to half that of the EC.

Barley was one of the basic crops of early irrigated agriculture in Mesopotamia and Egypt and increased in importance when the soils became more saline (Harlan, 1979). It was first cultivated about 10,000 years ago in the Middle East and reached Spain 3,000 years later before spreading rapidly throughout Europe. Wheat began to replace barley as a staple human food in classical times and in the first century AD, it was noted by Pliny that 'barley bread was much used in earlier days but has been condemned by experience and now barley is mostly fed to animals' (Harlan, 1979). By Roman times, the agronomy of barley and its ecological requirements in the Mediterranean region were apparently well understood to judge by the writings of Cato, Columella, Pliny and Varro (White, 1970). By the 11th century AD the Roman experience had been further refined by the Andalucian agronomists who developed appropriate rotations and irrigation policies for southern Spain (Bolens, 1974). Indeed, further developments in barley cultivation had to await the revolutions in chemical crop protection, plant breeding and mechanisation of the twentieth century. The history of barley cultivation in northern Europe is less well known. In Europe, barley is now mainly used to fatten cattle or in the brewing and distilling industries (see section 3.4).

2. Methods

2.1 Methodology

The project involved the collection, evaluation and compilation of four distinct types of data from the EC countries:

1. Physiological data which are either independent of, or directly related to, environment, such as rooting depth. These data were found by searching the relevant literature.

2. General agronomic data at the NUTS II level such as the range of dates of harvest. These data were obtained from a postal questionnaire, from personal contacts and by a careful selection of data from the literature.

3. Detailed information from individual crop trials, such as time from sowing to harvest, which cannot be obtained from averaged figures. These data were obtained by searching the literature. Much of the physiological information in the literature is independent of location so complete geographical coverage is unnecessary.

4. Agricultural statistics from Eurostat, FAO and national statistical offices.

Information in the first three categories was also collected from areas outside the EC (Czechoslovakia, south east Norway, Syria) as a check on information collected from regions at the boundaries of the EC and to ascertain the limits to barley performance set by severe soil and weather conditions.

General information was obtained from the textbooks on barley by Briggs (1978) and Rasmusson (1985), the crop science textbooks of Petr *et al.* (1988) and Brouwer (1972) and the agroecological atlas of cereal growing in Europe (Thran & Broekhuizen 1965; Broekhuizen 1969) but the book on barley by Molina Cano (1990) had not been published at the time of writing. Climatic data were obtained from the tables of temperature, relative humidity precipitation and sunshine for the world (Anon., 1982).

2.2 Physiological information

Surprisingly little information was found at a mechanistic level for a number of key processes, such as the duration of phenological stages and the development of the leaf canopy, although empirical approximations were available for a limited subset of varieties and locations. Even when information was available, it could not always be relied upon since some assessments are inherently subjective. This problem was exacerbated by the lack of common agreement about the meaning and definition of key concepts such as 'mean yield', 'optimum', 'harvest index' and 'leaf area index'. Currently, definitions may even vary from research group to research group. An internationally agreed set of definitions and methods such as that proposed by Cihlar *et al.* (1987) for describing crops and soils in remote sensing studies is urgently required. Even where definitions are agreed upon, the measurement methods used may give different values. The estimation of potential transpiration is a good example of this. Sometimes the environmental factor with the greatest influence on the rate of a process is not routinely measured but can only be inferred from other data. The rate of emergence of cereals is closely related to the mean soil temperature at 20 mm depth but, for good technical reasons, only air temperature is available. It should be possible to link the two empirically to take account of topsoil texture, water content and date but this has apparently not yet been done in any comprehensive manner.

2.3 Agronomic information

It proved remarkably difficult to abstract useful agronomic information from the literature. The main problem was that data were usually only available at a field or farm level and were not necessarily representative of the region as a whole and so regional averages were liable to be in error. To overcome this problem, an agronomic questionnaire was compiled and sent to more than 100 individuals or organisations in all parts of the EC. Instructions were given to complete it for a specified NUTS II region and to indicate for which other neighbouring regions the responses were valid. Completed questionnaires were received from 51 regions and from south east Norway. In several cases, forms were received from two independent sources for the same region allowing a comparison to be made. Completed questionnaires were checked for compatibility with questionnaires from neighbouring regions. The information collected was keyed into an ORACLE relational database for easy retrieval and compilation into tables by region. In the future it may be possible to use satellite imagery to obtain estimates of regional variation in some of the spatially variable attributes, such as date of sowing. It is important to consider what is meant when an agronomic statement is said to be true. In theory, the most useful assertions would be ones that were universally true, that is for all possible cultivars, climates, sowing dates and farming systems. However, it is impossible to test such an assertion in the current state of knowledge. Indeed, a universally true statement would suffer from being too vague or subject to so many conditions that its utility would be diminished. For example, the maximum altitude at which barley is regularly grown in each region of Europe is lower than the highest altitude at which it has ever been grown due to a combination of edaphic, meteorological and economic circumstances in particular locations and years. If the altitudinal limit were to be raised to take account of all these cases, its usefulness in delineating areas where barley is grown would be reduced without improving significantly estimates of total barley production. In this volume, statements are considered adequate representations of reality if they hold for at least 90% of the corresponding current EC barley area. In practice, the actual 90% boundary conditions for the various assertions could not be evaluated from the available data and had to be estimated subjectively.

2.4 Agricultural statistics

The accuracy and interpretation of barley statistics are affected by two factors in addition to those related to the survey methods employed (see also section 4.7). The most important problem is that about half the barley produced (data for EUR10) is used for stock feed on the farm of origin and is thus not traded. Consequently, estimates of production from this source are unreliable since harvests may be assessed by the farmer in terms of approximate volume of grain rather than by weight. The second complication is the existence of fodder barley, which is cut at the dough stage of grain development (about four weeks before grain harvest) for making silage. However, it is not grown widely in the EC, except perhaps in parts of the Mediterranean zone, since maize is a better alternative in hotter regions and grass in cooler, wetter parts. Fodder barley has not been considered in this inventory.

Part II

GENERAL DATA AND INFORMATION

3. Geographical distribution of barley in Europe

3.1 Distribution

Barley is an early maturing grain crop with a growing cycle that can be as short as 90 days, which is more tolerant of salinity and dry conditions than the other temperate cereals and which can give high yields under the cool, wet conditions typical of the more oceanic parts of north west Europe. Wheat or maize are generally preferred when conditions are favourable for their growth. Although barley is grown in virtually all the NUTS II regions of the EC, more than 80% of the area occurs in just five countries, Denmark, France, Germany, Spain and the United Kingdom (Fig.2). The same countries are responsible for almost 90% of total EC barley production (Fig.3). At a NUTS II (or unsubdivided NUTS I) level, 27 regions harvested more than 1 000 km^2, all except Ireland being within the five major barley producing countries (Appendix 2, 4) and 39 less than 100 km^2 (Appendix 2, 4). Within some heterogeneous NUTS II regions, NUTS III regions with less than 100 km^2 of barley were also identified (Appendix 3) although data at this level were not available for all countries. Maps of Europe showing regions with high barley areas give a misleading impression of the distribution of barley because administrative regions differ in size by more than two orders of magnitude. A more accurate impression of distribution is given by plotting barley area as a percentage of land area at the NUTS II level (Fig.4, Appendix 4). The estimates of barley area were obtained from Eurostat or from National Statistical Offices and the land areas were taken from Eurostat or from Munro (1988). Year to year variation in harvested area arises from two sources, a trend over time in response to socio-economic, technological or climatic changes and a fluctuation due to weather. For NUTS II region which show no discernable trend the coefficient of variation of harvested area ranges from 1.5% in humid areas to 5% in dry areas.

Since 1938 there have been large changes in the relative importance of barley compared with other cereal crops (Table 1). Since 1930 the area of barley in the countries which now constitute the EC has more than doubled from 55,680 to 122,340 km^2 (1988). In the same period, the wheat area has fallen slightly (183,510 to 155,340 km^2) and oats and rye have declined drastically (109,890 to 16,820 km^2 and 70,490 to 9,190 km^2 respectively). The reduction in area of oats is largely due to the reduced requirement for horse feed consequent upon the mechanisation of agriculture.

TABLE 1. BARLEY AS A PROPORTION OF THE TOTAL CEREAL AREA. DATA FROM FAO PRODUCTION YEARBOOKS.

	YEAR					
COUNTRY	1930	1950	1960	1970	1980	1988
B/L	0.05	0.16	0.20	0.38	0.42	0.35
D	0.08	0.13	0.21	0.29	0.38	0.39
DK	0.30	0.38	0.65	0.78	0.87	0.73
E	0.22	0.21	0.20	0.29	0.47	0.54
F	0.07	0.11	0.22	0.31	0.27	0.21
GR	0.13	0.13	0.11	0.19	0.22	0.18
I	0.03	0.04	0.03	0.03	0.07	0.10
IRL	0.13	0.13	0.31	0.57	0.82	0.77
NL	0.08	0.12	0.16	0.29	0.24	0.32
P	0.06	0.07	0.07	0.08	0.06	0.08
UK	0.19	0.25	0.44	0.61	0.60	0.48

FIG. 2 THE MEAN HARVESTED AREA OF BARLEY IN THE COUNTRIES OF THE EC, 1986-1988. DATA FROM FAO PRODUCTION YEARBOOKS.

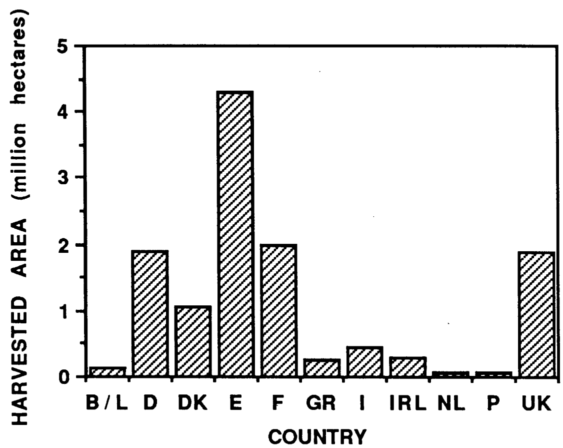


FIG. 3 THE MEAN PRODUCTION OF BARLEY IN THE COUNTRIES OF THE EC, 1986-1988. DATA FROM FAO PRODUCTION YEARBOOKS.

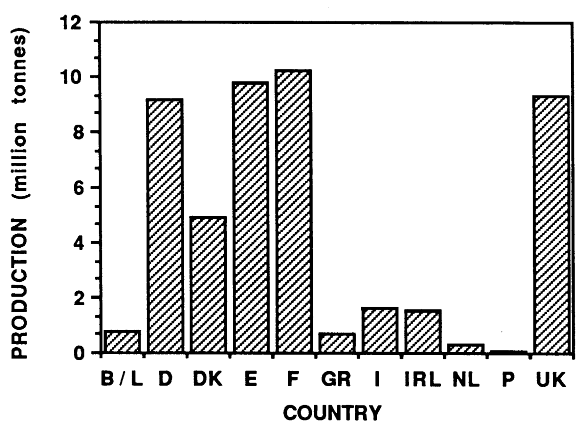
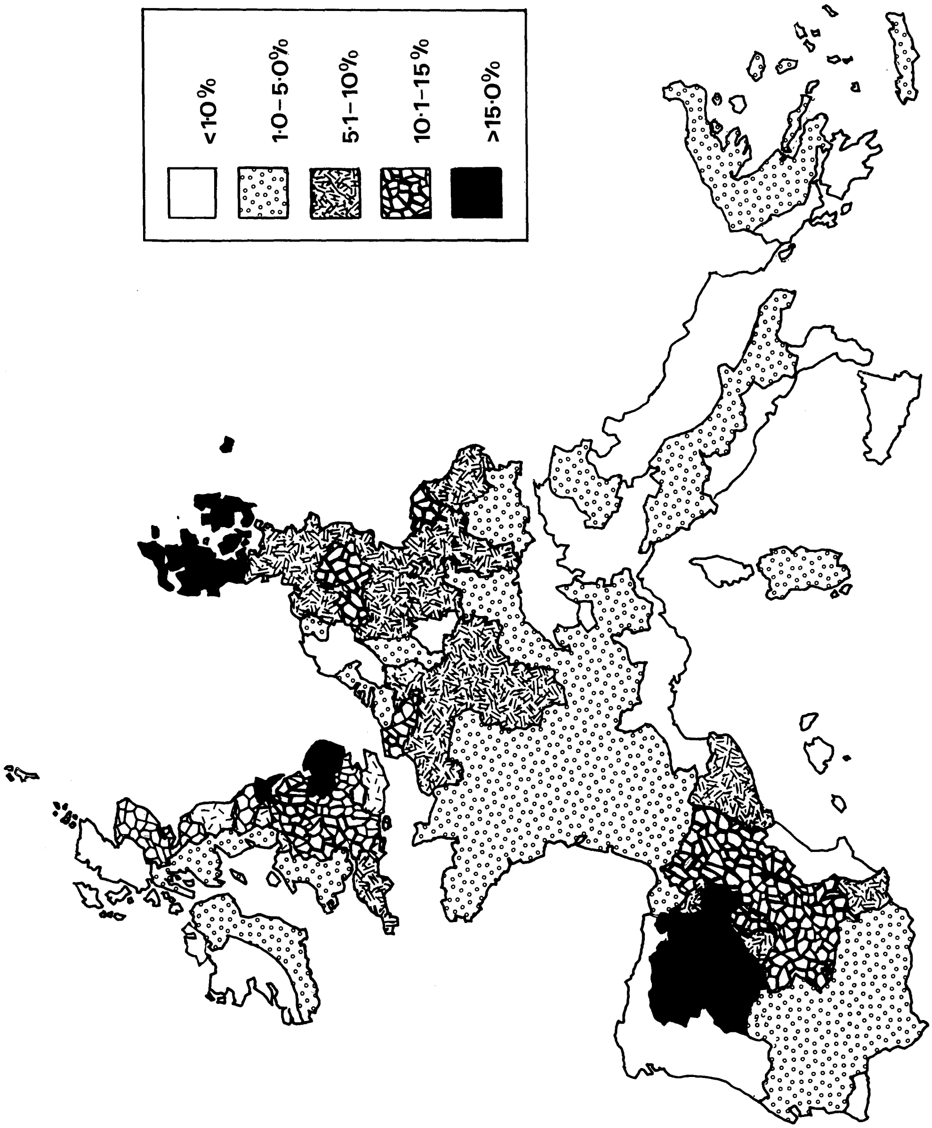


FIG. 4 HARVESTED BARLEY AREA AS A PERCENTAGE OF TOTAL LAND AREA BY NUTS II REGION.



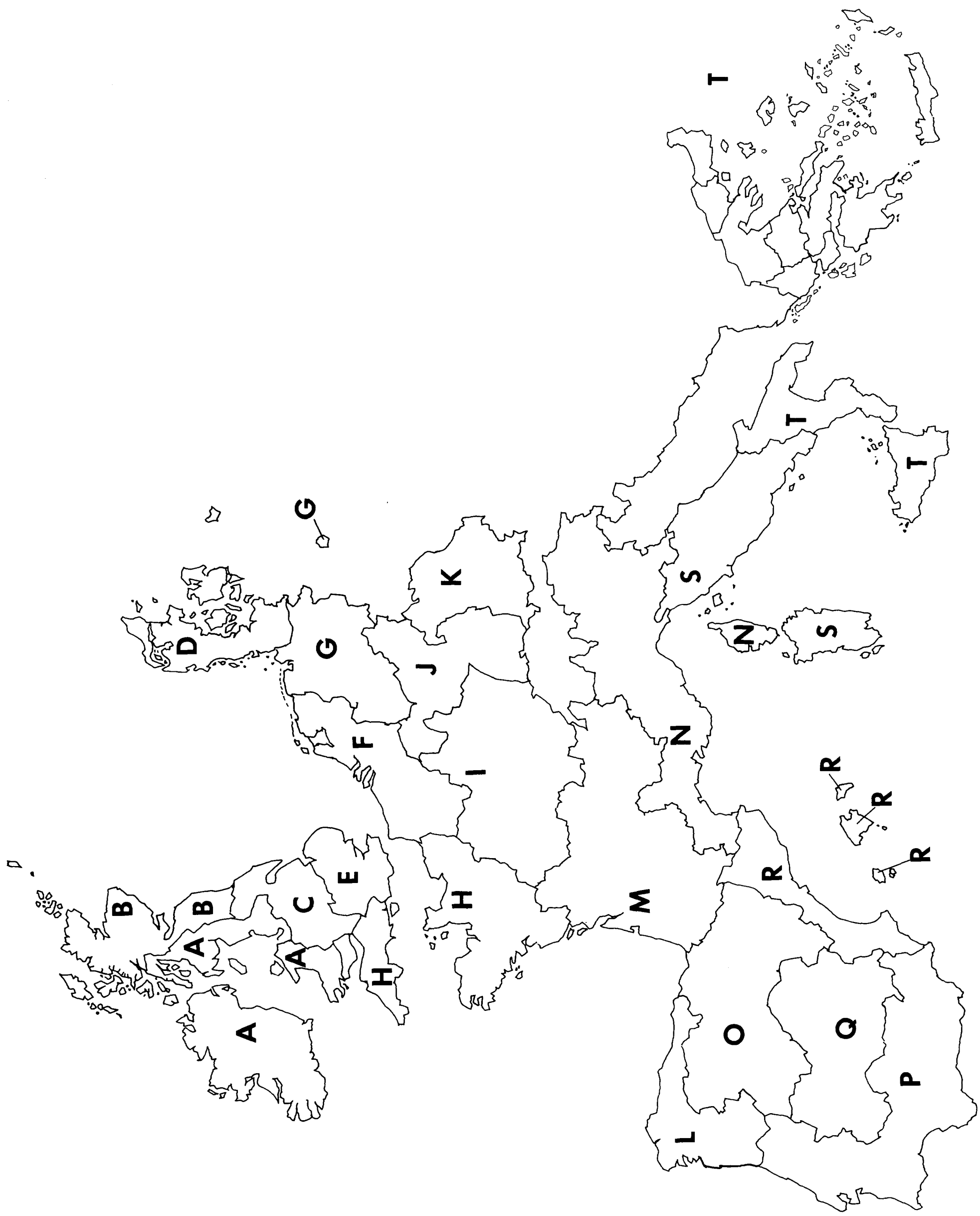
For the present project the countries of the EC were divided into twenty-one aggregations of NUTS regions (Fig.5; appendix 5). These regions were manually identified using a series of rules applied in the following order of priority:

I. regions should contain either very little or approximately 1,000 km^2 of barley.
II. regions should span no more than five degrees of latitude to minimise differences due to photoperiod.
III. boundaries should follow those of administrative regions at the NUTS II or III level.
IV. boundaries should follow major topographic features.
V. boundaries should separate regions with different farming systems.
VI. regions should be homogeneous with respect to the thermal time and precipitation between March 1 and June 30.

The position of the boundaries between the aggregated regions is inevitably subjective since even a rigid mechanical application of the rules would not have produced a unique solution. The classification adopted is not the optimum one for other crops because rules I and V are crop specific and rule VI would have to be modified to take account of the timing of critical stages in crop phenology. For example, conditions after June 30 are important for potato growth in some regions. Irrigation is also much more important for the potato crop and this has the effect of altering the apparent climatic restraints. The data held on ORACLE were recompiled and aggregated according to the new regions. Most of these regions were represented by questionnaires from several NUTS II regions. However, no information was collected from areas L (north-western Iberia) and U (the oceanic islands) which are unimportant producers of barley. Area U has not been further considered in this volume but estimates have been made for area L based on returns from neighbouring regions and from an examination of climatic data.

In regions such as M (south-west France) and T (south Italy and Greece) altitude varies considerably over relatively short distances leading to complex farming patterns. Indeed in Greece, the agricultural statistical service recognises three topographical categories (level, semi-mountainous and mountainous communes) in its presentation of information. This variation must be considered when representative climatic data are derived for each region.

FIG. 5 BARLEY PRODUCING REGIONS IN THE EC. THE CONSTITUENT NUTS REGIONS ARE GIVEN IN APPENDIX 5.



3.2 CLIMATIC FACTORS

Barley can be grown virtually everywhere in Europe on land classified as arable. On a large scale, only those areas classified as having a cryic or pergelic thermal regime or a perudic moisture regime (Tavernier & van Wambeken, 1985) should be excluded. In northern Norway at latitude 67°N the average thermal time from sowing to yellow ripeness (growth stage 87) of spring barley is 1,210°C d (base temperature 0°C) and to harvest, an estimated 1,350°C d (calculated from data in Valberg & Retvedt, 1974). However, since harvest occurs before the temperature falls to the base temperature and years vary in temperature a minimum mean annual accumulation of thermal time of 1,800°C d is a more realistic limit. Data from Iceland and Alaska support this figure although the exact requirement for thermal time will vary according to photoperiodic regime. Data from the questionnaire responses suggests that the average thermal time from sowing to harvest is about 3,300°C d in Sicily so perhaps appropriate temperature limits would be 1,800°C d at latitude 67°N and 3,750°C d at latitude 38°N. Because both the date of sowing and latitude change with location, linear interpolation between these limits would be unwise. However, there can be few arable areas where annual thermal time is too low to allow barley to be grown.

Current winter barley cultivars are sufficiently frost hardy to allow their use wherever the mean air temperature of the coldest month is greater than -2°C provided that sowing can be completed early enough in autumn to permit the development of a strong root system (see section 4.5). Spring barley is normally sown after the last killing frosts and so the risk of frost damage is not an important factor in its distribution (see section 6.4). Both spring and winter barleys are tolerant of dry heat although damage can be caused at temperatures above 30°C (see section 6.6). There are no regions in the EC with a climate which is hot and humid enough to be detrimental to barley growth (Klages, 1942).

Limits set by rainfall are complex since the effects of evaporation and soil type must also be considered. Barley, which is more tolerant of drought than wheat, can be grown without irrigation where the mean annual rainfall exceeds 250 mm. In the EC only parts of south east Spain fall below this figure. Wild barleys still grow in the upland areas of the eastern Mediterranean region such as in Syria where the annual rainfall averages 250 mm. When ungrazed, such stands give an average yield of 0.6 t ha^{-1}, which is about 60% of the mean yield of cultivated barley in Portugal. In many environments, the short growing season and the availability of varieties suitable for sowing in autumn, winter and spring allow the completion of the growth cycle before severe drought occurs. In areas with a maritime climate and a mean annual rainfall of more than 1000 mm, excess water, particularly at sowing and harvest time, is a more important problem. Such places, however, are unlikely to have significant arable agriculture.

Daylength does not set a limit to barley cultivation in Europe because there is a range of cultivars with the required responses. However, daylength does have a major effect on the duration of development phases (see section 6.5). Barley is a quantitative rather than a facultative long day plant so progress to flowering does occur in short days but at a slower rate. Some cultivars are day neutral.

The maximum altitude where barley is grown varies across the EC, being lowest in areas with a maritime climate and highest in continental areas (Table 2). In many regions the upper limit to barley cultivation is set by temperature but in others the risk of climatic hazards and the lack of soil in mountain areas are more important. In the wetter parts of North-west Europe, the upper limit to barley growing is set by excess water rather than by low temperature. The high rainfall results in delayed sowing, a slow warming of the soils in spring, low levels of solar radiation and difficult harvests. Because of the danger of damage during winter, the altitudinal limit of autumn-sown barley tends to be lower than that of spring-sown barley.

TABLE 2. THE MAXIMUM ALTITUDE (m) AT WHICH BARLEY IS GROWN REGULARLY.

region	altitude	region	altitude	region	altitude
A	200	H	300	O	1,200
B	300	I	450	P	2,000
C	300	J	800	Q	1,500
D	140	K	1,000	R	900
E	300	L	500	S	900
F	300	M	1,200	T	800
G	500	N	900		

3.3 Agronomic factors

At the farm scale, whether or not barley is grown in a particular field may depend on the weeds, pests and diseases encountered. These are unlikely to prevent the growth of barley in any area but may force the adoption of a particular rotation thus reducing the area that can be sown to barley in any one year. Certain areas are noted for the production of malting quality barley. In areas without livestock, wheat or maize tend to be the preferred crops as they outyield barley when growing conditions are favourable. Over the course of time the area of barley grown has increased, largely because of an increase in numbers of beef cattle. Barley is not mentioned in Zola's novel 'La Terre' which describes life in the Beauce region of France (R2242, R2246) in the late 19th century, but there is a great emphasis on wheat and, to a lesser extent, rye and oats. Wheat is still the dominant cereal in that region but barley has largely replaced oats and rye.

Approximate rules can be formulated to predict the situations in which other cereals are preferred to barley. However, these preferences tend to reduce the proportion of arable land sown to barley rather than to remove it entirely and economic considerations are even more important (section 3.4). Rye may be preferred in cold regions with sandy soils; oats in areas with more acid soils where the climate tends to be cool and wet; maize in hot areas where there is adequate rainfall or where irrigation is available and where stock feed is needed; wheat on the deeper, finer textured soils where there is sufficient water; sorghum in hot, dry regions.

3.4 Economic factors

The EC currently (1986/87) produces 17% more barley than is required for self sufficiency. Small amounts, mainly of malting quality, are imported. The balance of about 20% is exported or is stored. There are two main uses for barley in Europe: in the manufacture of beer and whisky and as stock feed. About 14% is used industrially mostly to produce malt for the brewing industry although some is used in the manufacture of whisky. The production of malting barley, for which there is a price premium, is localised in certain areas of the EC. The market for malting quality barley has remained relatively static over the past decade. The market for stock feed has expanded and now takes 79% of the annual barley production in the EC. Both wheat and barley are used as concentrated sources of metabolisable energy for stock and considerable substitution of the one for the other is possible. Both wheat and barley are deficient in the amino acid lysine which is necessary for healthy growth of stock. Considerable research has been carried out into ways of increasing the lysine levels in barley with the result that several high lysine lines such as Hiproly are available. However, these lines have not been incorporated into breeding programmes to any significant extent because there is a yield penalty of about 5% and because it is usually cheaper to improve the feed by adding a high protein supplement. In addition to these two main uses, seed production accounts for 5% of production and a small amount goes for direct human consumption. Changes in the market for barley in the future may include its increased use as a feedstock for the biotechnological industries such as bio-ethanol production for fuel. On the other hand, action to reduce surpluses should lead to less barley being grown in marginal areas.

Farmers' decisions to grow barley depend on the relative profitabilities of barley and competing crops which depend in turn on the price of grain taking account of the possibility of achieving a premium for malting quality.

4. Agronomy

4.1 Types of barley

Barley is a grass of the sub-family Pooideae and the tribe Triticeae. Consequently it shares many attributes with its fellow tribe members wheat and rye and some with other grasses (see also section 9). Recent aims in breeding have been for high yield, stiff straw, early maturity, malting quality, resistance to fungal disease, especially powdery mildew (*Erysiphe graminis*), rusts (*Puccinia* spp.), smuts (*Ustilago* spp), net blotch (*Pyrenophora teres*), spot blotch (*Helminthosporium* sp) leaf blotch (*Septoria* sp) and rhynchosporium

(*Rhynchosporium secalis*), and resistance to barley yellow dwarf virus and barley yellow mosaic virus. High yield has been achieved more by an increase in harvest index than crop biomass (Riggs *et al.*, 1981).

The 1988 Common Catalogue of Varieties in the EC lists 411 barley cultivars. Unlike maize and soya, they are not readily classified by maturity date. Instead, barley cultivars are divided into winter and spring and six- and two-row types. These divisions are based on the presence or absence of particular genes and are thus fundamental characteristics. 'Winter' and 'spring' refer to particular genotypic characteristics and not necessarily to the time of sowing although autumn sowings are usually of winter types in North-west and Central Europe. The preferred types vary from country to country in the EC (Table 3).

TABLE 3. THE PROPORTION (%) OF THE BARLEY AREA SOWN TO SPRING AND WINTER TYPES. DATA FROM EUROPEAN BREWING CONVENTION (1989) FIGURES FOR GREECE ARE ESTIMATES.

COUNTRY TYPE	B/L	D	DK	E	F	GR	I	IRL	NL	P	UK
Spring	15	39	96	41	29	95	15	91	90	100	54
Winter, 2-row	0	23	2	12	26	4	8	9	2	0	42
Winter, 6-row	85	38	2	47	45	1	77	0	8	0	4

Winter types require a period of about two to ten weeks vernalisation (Briggs, 1978), that is temperatures between 0°C and 8°C, to trigger floral initiation. The exact degree of vernalisation required varies with genotype and photoperiod. If vernalisation is incomplete, floral initiation is delayed and sporadic and there will be a severe loss in yield. However, the vernalisation requirements of winter barley are only likely to be unsatisfied in mid or late spring sowings, which would be rare on a commercial farm. In fact, unless killing temperatures are a feature of the region, the actual date of sowing is a more important agronomic feature than whether a cultivar is a winter or spring type. Ellis & Russell (1984) showed that once the effects of frost damage and vernalisation were removed there was little difference in the performance of winter and spring types sown in south east Scotland simultaneously in autumn or spring. Although autumn or winter sowings tend to give higher yields and are especially advantageous in areas with summer drought, spring sowings do not require frost hardy varieties, may fit in better with local crop rotations, tend to have lower crop protection costs, do not act as a 'green bridge' for disease and are preferred for malting because of the lower nitrogen content of the grain. In North-west Europe, where there is a danger of frost damage, there has been a trend over the past decade towards autumn sowing, and thus winter types, because of the higher yields obtainable and the earlier harvest. More recently, there seems to have been a swing back in favour of spring barley because of the lower inputs of crop protection chemicals required. Twenty five years ago, Göpp (1963) noted that winter barley was mainly grown in Spain, Portugal and Italy and was not of any importance in the northern countries. Spring cultivars tend to have shorter development cycles than winter ones and thus are now preferred in Mediterranean regions where barley is sown in winter (November to February) to permit the crops to mature before the onset of the summer drought. Autumn sowings become less common as winter temperatures fall, for example at high altitudes and in regions with a continental climate.

Cultivars which give reduced yields due to incomplete vernalisation or frost damage in a particular region are excluded from recommended lists and so type of barley is often confounded with geographic location. Consequently, the inclusion of type-specific (winter/spring) variables in a model for predicting barley yield in addition to date of sowing is unlikely to improve regional yield estimates significantly.

Barley ears consist of spikelets in groups of three at each node of the rachis. In two-row types the lateral spikelets are sterile and rudimentary so do not produce any grain, whereas they are fertile in the six-row types. Morphologically, six-row types support fewer ears m^{-2}, although there are more grains in each year (Table 11), and tend to have larger leaves than two-row types. They also tend to be more frost-hardy and drought-tolerant. Most, but not all, of the six-row varieties currently cultivated in the EC are winter types. In the UK and Ireland more than 90% of the winter barley sown is 2-row whereas in Belgium, Spain, Italy and the Netherlands the corresponding figure is less than 20% (Table 3). Although these geographic differences have been explained in terms of the greater tolerance of six-row types to environmental extremes, the preference by maltsters for 2-row types and the traditions of farmers and local plant breeders are more important.

Although barley cultivars do differ in their tolerance to dry conditions, any classification made on this basis is likely to be confounded with geographical location as farmers in dry areas tend to grow the cultivars which are most resistant to drought. The fact that 68% of the cultivars on the E.C. Common Catalogue list (December 1988) only appear on the list of one country and that fewer than 5% appear on the lists of more than four seems to support the assertion that barley varieties are well adapted to local conditions. However, it seems more likely that as cultivars are marketed more widely by the international seed trade they may be found suitable for regions other than the one of origin. In this context it is interesting to note that of the 17 barley cultivars on the 1990 Scottish recommended list (SAC, 1989), one was bred in Scotland, two in the Netherlands, three in Federal Germany, five in France and six in England. A division into feed and malting types, such as is adopted for the Spanish agricultural statistics, was rejected because it was not based on fundamental genotypic differences. The varieties used for malting vary from country to country and even from year to year and all malting varieties can be used for stock feed. However, malting barley is treated differently from feed barley particularly with respect to the timing and amount of nitrogen applied.

4.2 AGRICULTURAL PRACTICES

4.2.1 *Crop rotations*

In Europe, barley can be grown as a continuous culture but is more commonly grown in rotation with other crops. Rotations in many parts of Europe are now more flexible than they were twenty years ago and barley can be preceded and followed by a wide range of crops. Information collected from the questionnaire responses was evaluated on a regional basis to provide estimates for the proportion of the barley area preceded by different crops (Table 4a,b). Because of the way in which the data had been collected it was not considered appropriate to average the questionnaire responses for regions where there appeared to be considerable variation in rotational practices. Generally the median was used as a first approximation but it was modified on the basis of knowledge of the geographical distribution of the crops involved and of the estimates for neighbouring regions. The estimates were rounded to the nearest 5% and adjusted to sum to 100%. The data in Table 4 could be used in modelling yield if a link could be established between crop performance and the previous crop (disease, nitrogen status, date of sowing). Table 4 could also be used to devise rules to aid in the interpretation of satellite imagery such as 'if the region is T and the previous crop was potato then the current crop cannot be barley'. Ideally another table is needed to show the probability of barley following various crops but this cannot be derived from existing data.

Barley often follows winter wheat in a sequence and there may be two or three years of barley one after the other. Where strict rotations are employed they can range from three to seven years in length, the longer cycles being commonly associated with the use of grass breaks. Rotations are employed largely to control weeds, pests and diseases. Barley itself is less badly affected by soil-borne pathogens than wheat and it may be grown between wheats to reduce the effect of the soil borne disease take-all (*Gaeumannomyces graminis*). Spring sown barley fits well into many rotations but autumn sowings depend on the previous crop being harvested sufficiently early. In north-west Europe, winter barley is unlikely to be grown unless the ground is free by October 15. In northern Europe and at least as far south as the Pays de la Loire (R251) in France, barley is sometimes undersown with grass or other forage crops. After harvest the forage crop is fertilised and allowed to grow through till it is grazed or cut in the following year. In areas where soils have to be limed to compensate for a reduction in pH due to leaching of calcium, barley is often the first crop after the pH has been increased by liming and follows a crop more tolerant of acidity such as oats or potatoes. Barley may alternate with fallow in Greece, central and southern Spain and southern Italy.

Continuous barley can be defined as more than three consecutive years of barley growing in the same field. This system is generally practised either for reasons of economic efficiency or because there is no alternative. In north-west Europe there has been a move back from the simplified continuous systems of the 70's to more complex rotational systems to reduce the need for crop protection chemicals and to counter the deleterious effect on soil structure. In some parts of Europe, for example Castilla-Leon (RB41) in Spain, continuous barley is still regularly grown because there is no suitable alternative crop. Long term trials on Hoosefield at Rothamsted Research station (R7512) in England have shown that spring barley can be grown successfully for 100 years in succession on suitable soils provided weeds are controlled although the yields are normally less than in a rotational system. Yield losses from continuous barley seem to be least on calcareous soils. Autumn sown barley is less commonly grown continuously because of the difficulty of controlling perennial grassy weeds such as *Elymus* (formerly *Agropyron*) *repens* except in some upland situations where other crops would be harvested too late to allow successful establishment of the barley.

TABLE 4A. THE PROPORTION OF THE AUTUMN- AND WINTER-SOWN BARLEY AREA PRECEDED BY VARIOUS CROPS.

REGION	PRECEDING CROP											
	Wh	Ba	Ma	OSR	Su	Po	SB	So	Lu	PB	Gr	Fa
A	20	40	0	+	0	5	+	0	0	+	35	0
B	5	75	0	5	0	5	0	0	0	+	10	0
C	40	50	0	+	0	+	5	+	0	0	5	0
D	20	20	0	25	0	0	0	0	0	25	10	0
E	45	35	0	5	0	0	0	0	0	5	10	0
F	60	+	+	0	0	35	+	0	0	5	+	0
G	75	15	5	5	0	+	0	0	0	0	0	0
H	15	60	+	0	0	0	0	0	0	5	20	0
I	55	35	0	0	0	0	10	0	0	+	0	0
J	80	5	0	10	0	5	0	0	0	+	0	0
K	55	15	5	5	0	5	5	0	+	5	5	0
L	?	?	?	?	?	?	?	?	?	?	?	?
M	80	5	0	10	0	0	0	0	0	5	0	0
N	35	55	0	0	0	0	0	5	0	0	5	0
O	15	30	5	0	0	0	0	0	0	0	0	50
P	10	10	0	0	50	0	0	0	0	+	0	30
Q	10	20	5	0	5	0	0	0	0	0	0	60
R	10	85	0	5	0	0	0	0	+	+	0	0
S	50	0	30	0	0	0	0	0	20	0	0	0
T	70	10	0	0	0	0	0	0	0	0	0	20

Wh	wheat	SB	sugar beet
Ba	barley	So	soyabean
Ma	maize	Lu	lucerne
OSR	oilseed rape	P/B	peas and beans
Su	sunflower	Gr	grass
Po	potatoes	Fa	fallow
+ =	less than 5%	0 =	not registered in the survey

TABLE 4B. THE PROPORTION OF THE SPRING-SOWN BARLEY AREA PRECEDED BY VARIOUS CROPS.

REGION	PRECEDING CROP											
	Wh	Ba	Ma	OSR	Su	Po	SB	So	Lu	PB	Gr	Fa
A	10	50	0	+	0	10	5	0	0	+	25	0
B	10	65	0	5	0	5	0	0	0	+	15	0
C	20	65	0	+	0	+	10	0	0	+	5	0
D	30	50	0	+	0	+	15	0	0	+	5	0
E	20	65	0	5	0	0	0	0	0	5	5	0
F	40	5	+	0	0	15	35	0	0	5	+	0
G	30	30	35	+	+	0	5	+	0	0	0	0
H	25	60	+	0	0	0	+	0	0	+	15	0
I	60	40	+	+	0	0	0	0	0	0	+	0
J	60	10	10	+	0	+	10	0	0	10	+	0
K	40	30	20	+	0	5	+	0	+	5	0	0
L	?	?	?	?	?	?	?	?	?	?	?	?
M	70	30	+	+	0	0	0	0	0	0	+	0
N	0	0	100	0	0	0	0	0	0	0	0	0
O	50	50	0	0	0	0	0	0	0	0	0	+
P	10	10	0	0	50	0	0	0	0	+	0	30
Q	30	50	0	20	0	0	0	0	0	0	0	0
R	10	85	0	5	0	0	0	0	+	+	0	0
S	15	0	85	0	0	0	0	0	0	0	0	0
T	70	10	0	0	0	0	0	0	0	0	0	20

4.2.2 *Field preparation*

The degree of cultivation needed is similar to that required for wheat and depends primarily on soil type. Most evidence indicates that deep ploughing to 200 or 250 mm is unnecessary for barley crops except for occasional subsoil disturbance to aid drainage of heavy soils or to disrupt compact layers that may have arisen from previous cultivation damage. Ploughing is largely employed to control perennial weeds such as *Elymus repens* since barley can be established after only minimal cultivation. Direct drilling is possible where the soil structure is strong enough. Autumn sown barley may be rolled or harrowed in spring time. Spring sown barley may be rolled after sowing to consolidate light soils, maximise manganese availability, conserve moisture and lessen the risk of damage to harvesting machinery on stony soils.

4.2.3 *Establishment*

Most barley seed is drilled into the soil although some is still broadcast on the soil surface and harrowed in. The target plant population density (PPD) is 300 m^{-2} in areas where there is adequate water but lower PPDs are used where water shortage reduces growth significantly. Provided that there are more than 100 plants m^{-2} evenly distributed, PPD has a much lower effect on yield than has nitrogen rate. The seed rate employed varies from 100-250 kg ha^{-1} depending on the target PPD, the mean weight of the seed and the expected percentage establishment, which can vary from 40-90% depending on seedbed conditions. The depth of sowing is normally 25-50 mm, with depths at the higher end of the range being used in Mediterranean regions to put the seed in contact with moist soil. Sowing below 50 mm causes significant losses of primary tillers (Gates, 1989) and thus of yield. Hadjichristodoulos *et al.* (1977) found that sowing at 150 mm depth in Cyprus reduced establishment by 55% compared with sowing at 50 mm. The row width is typically 150 mm.

4.2.4 *Fertilisers*

Where the soil is well provided with phosphorus and potassium, only maintenance dressings of 60 kg ha^{-1} P_2O_5 and K_2O equivalent need be given. This fertiliser is normally applied in the seedbed and may be replaced by organic manures. The optimum rates of nitrogen vary considerably being less in low yielding sites and after crops that leave large amounts of residual nitrogen. The highest rates applied in normal practice are about 300 kg N ha^{-1}. Autumn sown crops may have up to 50 kg N ha^{-1} applied in the seedbed or shortly after emergence. but most of the nitrogen is applied in spring in one or two applications up to the first node stage (GS 31). Spring sown crops normally receive all the nitrogen before the onset of tillering (GS 21) and it is often applied in the seedbed. Granular fertiliser is normally applied by mechanical or pneumatic spreader and liquid fertilisers such as urea by spraying. Fertiliser is sometimes applied from aircraft but this is uncommmon.

4.2.5 *Crop protection*

The strategies for crop protection vary from country to country depending on the spectrum of weeds, pests and diseases encountered. Fungal diseases can be controlled by rotation of crops (eg eyespot), seed treatment (eg smut, mildew), the use of resistant varieties (eg mildew, rhynchosporium) or by chemical control. Almost all diseases can be controlled although it may not be economic to do so. Actual yield losses due to disease when averaged over a NUTS II region are generally less than 10% because of the availability of cost-effective fungicides. In the period 1969-73 in the West Midlands of England (R77), which predated the introduction of suitable fungicides, the average loss in yield due to mildew was 10%. Currently, losses are much lower because of better control measures including more resistant varieties. Fungal and viral diseases likely to lead to field loses of more than 10% if uncontrolled are given in Table 5 which has been modified from data in Smith (1988). Diseases currently controlled by seed dressing, cultivar resistance or other routine agronomic treatment have been omitted from Table 5. Foliar diseases have the greatest effect on yield in the vegetative period leading up to ear emergence and ear diseases during grainfill. Because ear photosynthesis is more important than in wheat, it is less important to keep the leaves clear of fungal infection after ear emergence. Seed dressings can be used to control covered smut, leaf stripe, net blotch, loose smut and powdery mildew. The incidence of disease depends on weather, soil type and the correspondence between barley phenology and the pathogen's life cycle (Lindner, 1989). Wet conditions favour yellow rust, brown foot rot and loose smut whereas warm dry conditions encourage the spread of powdery mildew. Rhizoctonia is important in coarse textured soils but eyespot and brown foot rot are greater dangers where the texture is finer. Late spring sowing increases the danger of severe attacks of mildew and brown rust. Virus diseases are also important. Barley yellow mosaic virus is an important soil-borne disease of areas of intensive cultivation such as the Federal Republic of Germany. Barley yellow dwarf virus appears to be becoming more widespread largely because recent mild winters have failed to control the aphid vectors.

TABLE 5. IMPORTANT BARLEY DISEASES IN EUROPE.

PATHOGEN	SYMPTOM	DISPERSAL	RANGE	YIELD LOSS
Erisyphe graminis	powdery mildew	W	EC	25%
Rhynchosporium secalis	leaf blotch	So/Se	EC except E	35%
Pyrenophora teres	net blotch	So/Se	EC except E,P	20%
Typhula incarnata	snow mould	So	?	?%
Fusarium culmorum	foot rot, ear scab	So/Se	EC	10%
Pseudocercosporella herpotrichoides	eyespot	So	D,DK,F,NL,UK	10%
Puccinia hordei	brown rust	W	EC except E,GR,I,P	15%
Puccinia striiformis	yellow rust	W	EC	30%
BYDV	barley yellow dwarf virus	aphids	EC	?%
BarYDV	barley yellow mosaic virus	So	B,D,F,UK	?%

Dispersal: W = wind; So = soil or trash borne; Se = seed borne; aphids = aphid vector
Yield loss is a typical loss per field if uncontrolled.

Weeds reduce the marketable yield by shading the young barley plants, making harvesting more difficult and contaminating the harvested grain. Broad leaved weeds mainly affect harvesting and the cleanliness of a grain sample although uncontrolled growth of chickweed (*Stellaria media*) can have a severe effect on crops sown in early autumn. Grass weeds on the other hand can decrease yield severely and it is not unusual for single fields to show losses of 20% from this cause. Blackgrass (*Alopecurus myosuroides*)is an autumn-germinating annual grass which is a problem with barley sown in early autumn especially on fine textured soils. Wild oat (*Avena fatua*) is an autumn- and spring-germinating annual grass that occurs on all soil types in North-west

Europe and is a problem on the coarser textured soils. Perennial grass weeds such as couch (*Elymus repens*), *Agrostis gigantea*, and *Agrostis stolonifera* are particularly a problem in autumn sown crops because there is often insufficient time for by cultivation. All over Europe methods are being used to reduce herbicide inputs. Techniques based on critical thresholds of weed infestation are now being supplanted by systems using combinations of low dose rate treatments. A well grown crop can compete well with weeds and once the stems start to extend, most crops are unlikely to require further treatment. Most herbicides for broad leaved weed control should in any case only be applied between growth stages 13 and 31 to avoid damage to the crop.

Although numerous pests attack barley they do not, in general, have as severe an effect on yield as the fungal diseases. The hessian fly (*Mayetiola destructor*) is probably the most important insect pest in the EC.

4.2.6 *Irrigation*

Only 3% of the EC barley area is currently irrigated but it is concentrated in a few areas. In Denmark, approximately 10% of the barley area in the Jutland peninsula (R903) is irrigated mainly because the soils have a low available water capacity. Elsewhere in North-west Europe it is rare for more than 5% of the barley area to be irrigated. In Spain in 1984, at the NUTS II level, the proportion of barley irrigated barely reached 12% and exceeded 10% only in Rioja (RB23), Aragon (RB24) and Murcia (RB62). There are several reasons for this low level of irrigation. In most areas the response of barley to irrigation is insufficient to balance the costs incurred especially when sowing dates have been chosen to allow the driest periods to be avoided. In areas where a response would be expected, the returns are likely to be less than from other crops such as maize. Moreover, in intensively irrigated arable regions, there are generally insufficient stock to justify the growing of barley to feed them (See also sections 4.6 & 7.5).

4.2.7 *Harvesting*

Barley is normally harvested by combine once the grain moisture content is less than 20% and ideally at 15%. Grain above 15% must be dried to that level or, in the case of feed barley, preserved with propionic acid to prevent deterioration. The moisture content at which the grain is actually cut depends on the probability of the continuation of good drying weather and the availability of combine harvesters. Typical work rates are 1.0-1.5 ha hr^{-1} per machine. In some parts of Spain and Greece, harvesting by hand is still carried out. Losses from machine harvesting are variable but in favourable circumstances are only 0.05 t ha^{-1}. After harvest the straw may be left in windrows for several days before baling, burning, or chopping and ploughing into the soil (see also section 7.6).

4.3 *Soil types*

Barley can be grown successfully on virtually all arable soils although it tends to be grown on the coarser textured soils with a pH (measured in water) between 6.0 and 7.0. Wheat has traditionally been grown on the finer textured soils, feed barley on virtually all soil types and malting barley on light to medium loams and on calcareous soils. Field plot experiments have shown that barley yields decline once the pH falls below 5.7. This threshold tends to be higher where the soil is low in phosphate and lower where the percentage of organic matter exceeds 15%. In actual practice, the threshold pH is often closer to 6.2 because of within-field variation. Within the EC, most arable areas with naturally low pH have been limed to a level where barley growth is possible except where a poorly buffered soil is subject to severe leaching caused by high rainfall (>1,000 mm). At the other end of the pH scale, barley can be grown at pH levels of 7.5 although micronutrients such as manganese may become unavailable and remedial nutrient application may be necessary.

The soil units from the 1:1,000,000 soil map of Europe on which barley cultivation is insignificant (based on Lee & Louis, 1985) are given in Table 6. This list is almost identical to the one for arable agriculture and excludes only 14% of the land area of the EC. Note that what may be suitable in one climatic zone may be unsuitable in another. The following soil phases are unsuitable: petrocalcic (unless there is 50 cm soil above the petrocalcic horizon); lithic (unless the parent material is Upper Cretaceous chalk); stony; gravelly; concretionary. Yield losses due to salinity are 10% for an ECe of 12-16 mmho cm^{-1}, 25% for 16-18 mmho cm^{-1} and 50% from 18-21 mmho cm^{-1} (Bernstein, 1964).

TABLE 6. SOIL UNITS ON THE 1:1,000,000 MAP OF EUROPE UNSUITABLE FOR BARLEY PRODUCTION.

GLEYSOLS:	calcaric, dystric and humic (except DK)
REGOSOLS:	eutric & dystric (except P)
LITHOSOLS:	eutric (except P), calcaric & dystric
RANKERS	
ANDOSOLS	ochric & vitric
PODZOLS:	orthic (except UK,DK,P),leptic, humic, placic
PLANOSOLS:	eutric (except P,GR)
HISTOSOLS:	eutric (except IRL,I,UK), dystric

Soil conditions in the EC suitable for barley growing are given in Table 7. The figures for the available soil water reserve do not appear to vary across the EC presumably because areas where PET is much greater than precipitation during the growing season tend also to be hot so that the growth cycle of barley is shortened and the total water requirement is thus reduced. Soil depth is given for parent materials which are not penetrated by roots. However, where the roots can penetrate a friable parent material the required depth of soil can be as little as 20 cm. For example, barley is grown in Poitou-Charentes (R253) on soils only 20 cm deep overlying Upper Cretaceous chalk.

TABLE 7. SOIL CONDITIONS FOR SUCCESSFUL BARLEY GROWING.

	GOOD	POSSIBLE	UNSUITABLE
TEXTURE	Medium fine Medium	Very Fine Fine Coarse Organic	None
HYDROMORPHY, WATER TABLE DEPTH (cm)	Temporary at 50-100 **OR** No hydromorphy	Temporary at < 50	Permanent at < 50
MAXIMUM AVAILABLE SOIL WATER RESERVE (mm)	> 80	40 - 80	< 40
SLOPE (%)	0 - 8	9 - 25	> 25
VOL % OF STONE (> 75 mm)	0 - 15	16 - 35	> 35
VOL % OF GRAVEL (< 75 mm)	0 - 15	16 - 35	> 35
DEPTH (cm)	> 100	40 - 100	0 - (20) 40

4.4 Rooting depth

Soil factors only have a major affect on yield after the crop is established. The rooting system is similar to that of wheat but is slightly less well developed. The extent to which the roots explore the subsoil appears to be of major importance explaining differences in yield from soil to soil. The deepest roots of spring sown barley can extend to a depth of 1.2 m (Russell, 1976) in sandy loams although comparatively few roots actually reach that depth and little water is removed from below 1.0 m. In dry conditions, all the available water in the top 1.0 m of soil can be utilised. In deep, loamy soils the roots of spring sown barley can reach 1.4 m (Breuning Madsen, 1985). In spite of the longer duration of growth the rooting depth of autumn sown barley (Gales, Ayling & Cannell, 1984; Bragg *et al.*, 1984) seems to be similar although roots can sometimes penetrate to 2.0 m. The roots start to extend significantly at the time of plant emergence and reach their maximum extent at ear emergence. Jakobsen (1976) found that the rate of increase of barley rooting depth (m d^{-1}) after plant emergence was given by:

$$dL/dt = 0.0025(T - 4)$$

where T is the temperature in °C.

Normally, 80% of the root dry weight is in the upper 0.15 m of soil and the total dry weight can reach 100 g m^{-2}. Soil and weather factors affect root and shoot growth differentially with the result that the proportion of plant biomass accounted for by roots varies between wide limits even after phenological stage is removed as a source of variation. Nitrogen level tends to affect shoot more than root growth whereas at high temperatures or at low irradiances root growth tends to be depressed. Danish investigations (Aslyng & Hansen, 1982) have shown that root growth is not possible if there is less than 5% colloidal material (clay and organic matter) in a soil horizon but such situations are uncommon. From the point of view of nutrition and water uptake, the length of root is more important than the weight. Root length can be estimated as the product of root biomass and specific root length (the length of root per unit root weight). The specific root length varies between 70 and 230 m g^{-1} according to phenological stage, growing conditions and depth in the soil and figure of 150 m g^{-1} is typical of crops at the ear emergence stage of development. Unfortunately, recent work has shown that in wheat only 5-25% of the total root length is actively involved in the uptake of nitrogen. The same is probably true of water uptake.

4.5 METEOROLOGICAL HAZARDS

High winds can be a problem especially in conjunction with heavy rain after ear emergence when entire fields of barley can lodge. This leads to lower yields, more difficult harvest and poor quality of the harvested grain. In windy areas of North-west Europe, straw strength and ear retention are important characters selected for in breeding programmes.

Abnormally dry conditions can affect yields in most parts of the EC. Spring-sown barley growing on soils with low available water capacities can suffer yield loss due to drought even in the wetter areas. Drought before ear emergence leads to fewer grains m^{-2} being produced and during grain fill to shrivelling of the grain, low thousand grain weight and consequent high screening losses. Inundation is a problem generally caused by heavy rain or rapid snowmelt on a site with impeded drainage due to soil compaction or a subsoil of naturally low permeability. Plants can be killed if they are flooded for more than 20 days during the period before the onset of tillering (Cannell *et al.*, 1984). This often occurs in patches of 1-20 m^2 within an otherwise healthy field. Hail can cause damage to barley crops but is only a significant problem south of latitude 50°N.

Temperatures above 30°C during anthesis and grainfill are less deleterious than in wheat (see section 6.6). Cold is not generally a major cause of plant death. Provided the crown region (which includes the stem apex) remains alive, barley can survive the loss of all its leaves due to frost. In winter barley, many leaves are damaged when the air temperature falls below -8°C, some plants are killed below -12°C and most plants are killed below -16°C (Nuttonson,1957). If the soil is insulated by snow or by crop residues, the critical air temperature is reduced since it is actually the soil temperature that is the controlling factor due to the location of the vital crown region 20 mm below the soil surface during the winter period. Air temperatures as low as -30°C have reportedly been survived in these conditions. A more serious problem is that of frost heave where developing root systems are severed when moist, medium textured soils freeze. In North-west Europe the plant population density of barley crops sown in November on land with fine, very fine or medium fine textured topsoils may be reduced by 75% for this reason if the minimum air temperature falls below -10°C. In areas where frost heave is likely to be a problem, autumn sowings are normally carried out early enough for the root system to develop the strength to withstand these forces.

4.6 Irrigation and water use efficiency

The water use efficiency of barley is greater than that of wheat. The key stages for irrigating barley are at sowing to allow successful establishment and at ear emergence to allow the survival of the developing grains (Sepaskhah, 1978). In a dry climate it is important that the amount of irrigation before and after ear emergence should be balanced. If the crop is well supplied with water in the period before but not after ear emergence more grain sites will be formed than can be filled and consequently the mean grain weight will decline and screening losses increase. Response to irrigation is often presented as the percentage increase in yield over unirrigated controls. However, for modelling purposes, a more useful figure is the ratio of unirrigated to irrigated yields since the irrigated treatment should correspond to the potential yield set by temperature and solar radiation. In the EC, the ratios of unirrigated to irrigated regional yield are available only for Spain. In 1984 the mean value of this ratio ranged from 0.17 in Murcia (RB62) to 0.84 in Navarra (RB22). There were no figures for irrigated barley in the wetter parts of Spain where the ratio should approach 1.00.

Water use efficiency (WUE) is the ratio of biomass to the amount of water transpired by or evaporated from a crop. WUE is a good predictor of biomass in conditions where growth is solely at the expense of soil water reserves. Unfortunately this situation is unusual in the EC. In Mediterranean environments, widely different amounts of biomass can be accumulated per unit of water used (Cooper, Gregory, Tully & Harris, 1987). In such climates, the soil surface is wetted frequently in the crucial winter period and direct evaporation can account for 50-80% of total evapotranspiration. Any management practice which encourages early plant growth will reduce the amount of water lost and thus increase dry matter production (Shepherd *et al.*, 1987). Figures for WUE in the literature range from 15 to 25 (Cooper, Keatinge & Hughes, 1983; Sepaskhah, 1978) consistent with the average of 15.9 kg ha^{-1} mm^{-1} quoted by Begg &

Turner (1976) for C_3 grasses such as barley. Multiplying an average WUE of 20 kg ha^{-1} mm^{-1} by the 300 mm likely to be evaporated by a crop of spring sown barley in the UK gives a predicted biomass of 6 t ha^{-1} and therefore a yield of about 3 t ha^{-1}, a gross underestimate. Cooper *et al.* also quote figures for transpiration efficiency, that is excluding evaporation from the soil surface, of 43 to 46 kg ha^{-1} mm^{-1}. Multiplying these figures by 300 mm gives predicted yields approaching 7 t ha^{-1} which are close to the actual values encountered. Transpiration efficiency is likely to be a better predictor of barley yield than WUE whenever the soil surface is frequently wetted.

4.7 YIELDS AND YIELD VARIABILITY

Mean country yields have been estimated by dividing production by harvested area (data from Eurostat). These estimates must be treated with caution since production and yield have probably been obtained using different samples and because only marketed grain is weighed accurately. There may also be differences in the methods used by the national statistical services. In Denmark, for example, complete surveys are only carried out in alternate years. Mean country yields averaged over nine years 1980-88 range from 1.36 t ha^{-1} for Portugal to 6.43 t ha^{-1} for the Netherlands (Table 8).

TABLE 8. MEANS AND COEFFICIENTS OF VARIATION (STANDARD DEVIATION/MEAN) FOR THE COUNTRIES OF THE EC.

COUNTRY	MEAN (t ha-1)	COEFF. of VAR. (%)
B	5.71	11.5
D	5.01	9.2
DK	4.63	13.2
E	2.33	22.4
F	5.36	9.8
GR	3.29	7.2
I	3.73	4.3
NL	6.43	8.6
L	3.48	15.7
IRL	5.40	11.4
P	1.36	16.1
UK	5.54	9.5

Coefficients of variation range from 4% for Italy to 22% for Spain. With the exception of Luxembourg, only Spain and Portugal exhibit CVs greater than 15%. These data can be grouped into two sets on the basis of mean yield. The Mediterranean countries, Spain, Portugal, Greece and Italy, all show mean yields less than 4.0 t ha^{-1} while the other countries exceed this value.

Since yields are consistently higher on some farms than on others the maximum yield declines as the area considered increases in size. The maximum recorded yield in the EC for a single farmer's field appears to be 12.3 t ha^{-1} (15% MC) for a crop of cv Plaisant winter barley growing on a fine textured soil in southeast Scotland (R7A11) in 1989. The NUTS II region with the highest recorded mean yield in the period 1980-1988 was Zeeland (R474) in the Netherlands which averaged 8.3 t ha^{-1} (15% MC) in 1984.

4.8 Quality standards

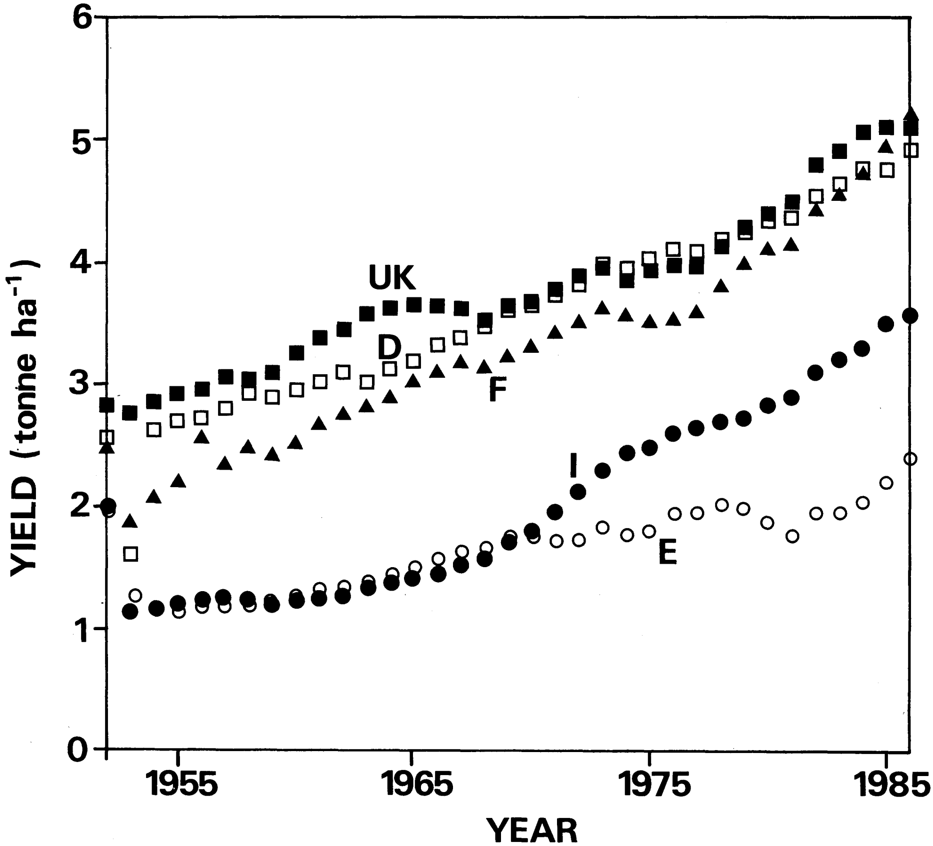
Quality standards depend on the use to which the barley will be put. Plump well-filled grains with a minimum of contamination are required for feed barley, . For malting barley the requirements are much tighter and samples not meeting them will be rejected. In addition to the feed barley standards, malting barley must have a high germination rate (this largely depends on the treatment during harvest and storage) and a low nitrogen content. A high nitrogen content leads to cloudy beer, can affect its flavour and reduces storage life. Moreover, an increase of 0.1% in nitrogen percentage (from 1.7%) reduces the malt extract by 1%. Brewers can combat the effects of high nitrogen malt but it is an expensive process. Although careful husbandry is necessary to produce quality malting barley, it is not sufficient on its own as the nitrogen content also depends on soil type and on the weather experienced. Two conditions must be satisfied to produce low nitrogen barley: the nitrogen released by the soil in the late stem extension, heading and grain fill phases should be as low as possible and the grain must be well filled to dilute the nitrogen taken up by the plants.

The first condition can be met by choosing a field with a cereal crop in the previous year and by avoiding organic soils. To fulfil the latter, the period of grainfill should ideally be cool without excess or shortage of water. However, areas such as north-east Scotland, Bavaria and Belgium where malting barley has traditionally been grown do not necessarily conform to both these criteria. It is likely that the real reason for the localisation of malting barley production lies in a tradition of brewing and that the development of rotations in which barley follows wheat or barley followed from this.

5. Technical progress

Yields of barley have increased dramatically over the past 30 years (Fig.6, appendix 6). Over this period, yields have risen regularly in France, the United Kingdom and in Federal Germany. In Italy, yields began to rise rapidly in 1968 and in Spain not till 1980. This increase is due partly to the general intensification of agriculture, particularly in the use of nitrogenous fertilisers and crop protection chemicals, and partly from the use of improved varieties. Average yields still seem to be increasing except in the UK where a plateau seems to have been reached. It is difficult to separate the effects of cultivar and input level since both have changed together. The initial increase in the use of nitrogenous fertiliser was only possible with the advent of shorter and stiffer strawed cultivars which did not lodge under high nitrogen régimes. This major change began in the 1930s when crosses between Gold, a Swedish landrace, and Hanna, from Czechoslovakia, were introduced. These new cultivars such as Kenia and Maja were characterised by higher yield, shorter stiffer straw and earlier maturity than existing cultivars. Selective herbicides and combine harvesters were introduced in the early 1950s but the effect on yield was small at first and possibly even negative. In 1963, the proportion of barley harvested with combine harvesters varied widely in the countries that now make up the EC (P & E 2%; DK 40%; F 65%; D 70%; I 75%; IRL & B 80%; UK 90%; NL 98%; data from Göpp, 1963) but the current figures are close to 100% in all countries. A recent study of barley yields in England (Gossen, 1988) has shown that the upsurge in barley breeding throughout Western Europe in the late 1950s and early 1960s did not begin to show in increased yields until the mid 1960s in the case of malting barley and a decade later for feed barley. Previous increases in yield were therefore largely due to technological change. The first commercial fungicide to control mildew was introduced in 1970 and the use of fungicides spread rapidly with a consequent effect on yield. However, the subsequent development of cultivars with disease resistance has not generally led to further increases in yield from this cause because of the effectiveness of the fungicides in use. Silvey (1978) estimated that between 1947 and 1975 about 30% of the increase in barley yields in the UK was due to cultivar. Most of this increase has arisen from improved harvest index rather than to an increased biomass at maturity. She also suggested that husbandry has had no apparent additional effect on UK yields since 1967 since the optimum responses to fertiliser, seed dressing and herbicides had been achieved. It is also worthwhile bearing in mind that the farmer's aim is not usually to maximise yields but to maximise profit. The trend in yield is further complicated by the switch from spring to the potentially higher yielding winter types which took place in the early 1970s in northern Europe, especially in the UK. The areas where barley was grown also underwent a change. Feed barley began to be grown in some traditional wheat areas and wheat began to be grown on the coarser soils formerly typical of barley. Barley also began to be grown on climatically marginal areas because of the availability of early maturing varieties and the support offered by the Common Agricultural Policy.

FIG. 6 MOVING FIVE YEAR AVERAGE OF BARLEY YIELDS 1950-1988. DATA FROM FAO PRODUCTION YEAR BOOKS



Part III

AGROMETEOROLOGY AND CROP PHYSIOLOGY

6. Meteorological influences on barley growth and development

6.1 Basic physiology

Production can be modelled in several ways. It can be considered as the product of the area harvested, plants m^{-2}, ears $plant^{-1}$, spikelet primordia ear^{-1}, % spikelet survival and mean grain mass or as the product of area harvested, the biomass at maturity (kg m^{-2}) and the harvest index. The second model, which was developed *inter alia* by Monteith (1981), has been elaborated by Russell & Ellis (1988). Biomass can be considered as the product of a rate and duration of growth. Growth can be considered as the product of photosynthetically active radiation (PAR; 400-700 nm) absorbed by the barley canopy and the dry matter: radiation quotient (DMRQ; Russell, Jarvis & Monteith, 1989) which represents the conversion of solar energy into crop biomass. The former depends on the incident irradiation, the leaf area index of the crop and to a lesser extent on the leaf angle distribution. When DMRQ is defined as the ratio of crop growth rate to the rate of absorption of PAR a value of 3.0 g MJ^{-1} has been found for the period from crop emergence to anthesis for many cereal crops in the UK not under severe water stress (Green, 1984). Few measurements are available for other parts of Europe but it is possible to calculate DMRQ using a modified form of an equation due to Charles-Edwards (1982) which assumes a classic hyperbolic light response curve of photosynthesis to irradiance and a sinusoidal diurnal variation in irradiance.

$$DMRQ = \frac{B \times 36.6 \times 10^6}{(((I + K)/F_{max}) + (1/\alpha))}$$

where B is the ratio between net and gross assimilation after allowing for respiration and turnover; 36.6 allows for the conversion from CO_2 to carbohydrate and for a reflection coefficient of 10% in the PAR wavebands; I is mean daily irradiance (W m^{-2}); K is a canopy light extinction coefficient; F_{max} is the light saturated rate of gross photosynthesis of a single leaf (µmol m^{-2} s^{-1}; α is the initial slope of the light response curve (µmol J^{-1}). Appropriate values of the parameters were found by setting DMRQ for area C where Green (1984) was working, to approximately 3.00, assuming a value of 4.0 for K (Gallagher & Biscoe, 1978), 0.60 for B and 224 for I (typical of the month before anthesis in area C) and optimising F_{max} and α taking account of relevant figures in the literature such as those in Biscoe *et al.* (1975). F_{max} was found to be 24 micromol m^{-2} s^{-1} and α, 0.27 micromol J^{-1}. Mean irradiances for the month preceding the mean date of anthesis for all sowings were calculated for each barley region using daylengths from the Smithsonian meteorological tables (Smithsonian Institution, 1966) and mean radiation receipts from CEC (1984). Values for DMRQ were then calculated for each region (Table 9). DMRQ ranges from a low of 2.68 g MJ^{-1} to a high of 3.10. These figures should be typical of the year 1980 but an increase is likely due to the change in atmospheric CO_2 concentration. Values of DMRQ were calculated for atmospheric concentrations of 330 and 400 vpm by assuming that the former level was typical of 1980 and that F_{max} was proportional to the atmospheric concentration less 50 vpm, which was assumed to be the CO_2 concentration in the interior of the leaf (Table 9). In all cases the DMRQ rises by approximately 10%. The actual effect is likely to be less since the canopy conductance for CO_2 transfer is likely to decline. Theoretical corrections for temperature are complex because respiration and photosynthesis respond in different ways. As a first approximation, DMRQ can be assumed to increase linearly from 0.00 at a temperature of 0°C to its maximum value at 10°C, to remain constant till 20°C and then to decline linearly to 0.00 at 40°C. However, the appropriate measure of temperature is not the daily mean since most photosynthesis occurs in the central part of the day. If temperature varies sinusoidally over the day and reaches its maximum two hours after solar noon the mean temperature of the central four hours of the day can be calculated using the equation:

$$T = 0.92\,Tx + 0.08\,Tn$$

where Tx and Tn represent the daily maximum and minimum respectively. This is the value that should be used to correct DMRQ.

TABLE 9. VALUES OF DRY MATTER: RADIATION QUOTIENT (g MJ^{-1}) BY REGION FOR TWO ATMOSPHERIC CARBON DIOXIDE CONCENTRATIONS.

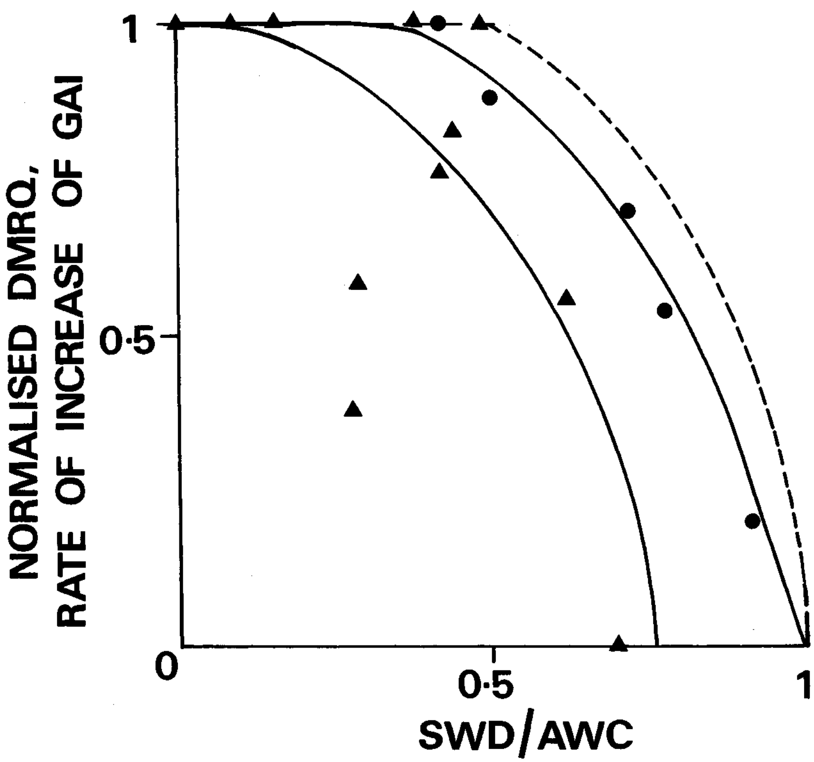
region	CO_2 concentration (vpm) 330	400	region	CO_2 concentration (vpm) 330	400
A	2.80	3.14	K	2.90	3.23
B	2.94	3.27	L	2.72	3.05
C	2.96	3.29	M	2.72	3.05
D	2.67	3.00	N	2.8	3.18
E	2.98	3.31	O	2.54	2.87
F	2.98	3.31	P	2.45	2.77
G	2.98	3.31	Q	2.28	2.60
H	2.68	3.01	R	2.31	2.63
I	3.10	3.43	S	2.45	2.77
J	2.90	3.23	T	2.76	3.09

After anthesis the DMRQ appears to fall to approximately 1.5 g MJ^{-1} (derived from data in Gallagher & Biscoe, 1978). There is apparently still no complete analysis relating the value of DMRQ to the fundamental processes of photosynthesis although many of the factors affecting DMRQ have been identified. DMRQ is reduced whenever lack of water induces stomatal closure to such an extent that photosynthesis is inhibited significantly. This effect has apparently not been quantified in the literature. Data from Leach (1980) were re-analysed to rectify this omission (Fig.7) by assuming that differences in growth rate between plots differing only in soil water status were due to variation in DMRQ whenever GAI exceeded 3.0. At this value of GAI almost all the incident PAR is intercepted. The ratio of actual to potential (that is when water was not restricting growth rate) DMRQ has been plotted against the ratio of soil water deficit (SWD) to available water capacity (AWC) to reduce the effect of differences in water release curves between soils of different texture. As the soil dried out, the ratio must have been underestimated as no allowance was made for root growth, which is less affected by drought than the above-ground parts measured, in the original paper. The DMRQ was corrected assuming that root weight was 20% of the total crop biomass and that root growth rate was independent of SWD (Fig. 7). The effect of SWD on corrected DMRQ is less than the effect on transpiration (Fig. 17), which is in accord with theory since the CO_2 diffusion pathway is longer than that travelled by water.

Key phenological dates for cereals are sowing, emergence, floral initiation, and anthesis but in a simplified model only two phases are needed: emergence to anthesis (or ear emergence, see section 6.6) and anthesis to maturity. Two environmental variables dominate any discussion of phenology, temperature and photoperiod. Temperature is often expressed as an accumulation, that is as thermal time, although there is controversy as to the most appropriate value of the base temperature. However, most workers (eg Ellis & Russell, 1988; Gate, 1989; Wright & Hughes, 1987) now use a base of 0°C. Most of the variation in the literature can probably be explained by two facts. First, the base temperature is derived using statistical techniques which are influenced by the frequency distribution of mean temperatures encountered and secondly, barley, like other grasses, develops at a rate depending on the temperature of the stem apex. Mean air temperature is a good index of apical temperature in most conditions but significant deviations can occur especially before stem elongation when the apex is close to the soil surface. Since development rates appear to decline above 28°C (Ellis *et al.*, 1988) temperatures higher than this should really be excluded from calculations of thermal time. The photoperiod to which barley is sensitive (Roberts & Summerfield, 1987) is the sum of daylength and twice civil twilight as defined in the Smithsonian meteorological tables (Smithsonian Institution, 1966).

The duration of the phase from crop emergence to anthesis is of great importance since the number of grains m^{-2}, which is set at anthesis, seems to be proportional to the crop biomass accumulated over the period (Dyson, 1977; Russell & Ellis, 1988). Indeed, some authors (eg Gallagher, Biscoe & Scott, 1975; Bouchet, 1982) have suggested that, barring meteorological or pathological damage, mean grain weight is essentially

FIG. 7 THE EFFECT OF SOIL WATER STATUS, EXPRESSED AS THE RATIO BETWEEN SOIL WATER DEFICIT AND AVAILABLE WATER CAPACITY, ON THE DRY MATTER: RADIATION QUOTIENT (CIRCLES) AND THE RATE OF INCREASE OF GREEN AREA INDEX (TRIANGLES) BOTH OF WHICH HAVE BEEN NORMALISED BY SETTING THE VALUE FOR CROPS FREELY SUPPLIED WITH WATER AT 1.00. THE DASHED LINE REPRESENTS THE DMRQ RATIO AFTER CORRECTION FOR ROOT GROWTH.



constant and that thus yield is largely determined by the time of anthesis. Russell & Ellis (1988) found that 71% of the variation in yields of spring sown barley in one trial could be attributed to the date of anthesis. At this time the biomass of a well-grown crop of barley is increasing by about 2% per day (Russell, 1988) so a ten day error in date of anthesis is equivalent to a 20% error in yield prediction. Dyson, who worked on spring barley in north east Scotland (R7A4), where grainfill is not usually limited by dry conditions, also found that yield was approximately equal to the biomass at ear emergence. After anthesis, grainfill occurs both from current photosynthesis and from translocation of reserves stored in the stem. Table 10 shows the stages of development at which the various components of yield are set.

Two aspects of development should be distinguished, stem apex development (Kirby & Appleyard, 1984) and the consequent external morphological changes (Zadoks, Chang & Konzak, 1974). Although the two development scales parallel each other to such an extent that the Zadoks scale can be used as an index of apical development, provided that a restricted range of locations, cultivars and sowing dates is considered, there is no exact one to one correspondence between them (Grant, 1984; Kirby & Appleyard, 1984). Considerable research has been carried out into the timing of crop development stages, but most studies have been limited in terms of the range of cultivars or environments used. Most of these studies (eg Kolbe, 1984) have concentrated exclusively on the Zadoks development stages. Although they are valuable sources of information, they do not provide the data on apical development necessary for the more mechanistic understanding of the process required. Consequently geographical extrapolation of these results must be carried out with caution. Comparatively few research groups have carried out comprehensive studies of apical development of barley in field conditions. Although most of these studies have been carried out in North-west Europe this does not necessarily present a problem of representativeness. The photoperiod at crop emergence, as defined above, ranges from 9.8-19.4 h at latitude 58°N but only from 10.7-13.7 h at latitude 35°N so that the photoperiodic conditions of southern Europe are a subset of those experienced in the north.

TABLE 10. STAGES WHEN PARTICULAR COMPONENTS OF YIELD ARE SET. THE RELATIVE IMPORTANCE OF EACH PERIOD IN ITS EFFECT ON THE VARIOUS COMPONENTS OF YIELD HAS BEEN ASSESSED ON A SCALE RUNNING FROM 1 (SMALL EFFECT) TO 3 (MAJOR EFFECT). WHERE THERE ARE DIFFERENCES BETWEEN AUTUMN AND SPRING SOWINGS, THE FIGURE FOR THE FORMER IS GIVEN IN THE UPPER PART OF THE SQUARE.

COMPONENT PERIOD	AREA SOWN	PLANTS /m^2	EARS/ PLANT	BIOMASS at MATURITY	MAXIMUM PRIMORDIA /EAR	%SURVIVAL OF SPIKELET PRIMORDIA	1000 GRAIN WEIGHT (g)	HARVEST INDEX
PREVIOUS SEASONS (ECONOMIC FACTORS)	2							
HARVEST OF PREVIOUS CROPS	3							
FIELD PREPARATION	3	1						
SOWING	1	2						
GERMINATION -EMERGENCE		3	1					
EMERGENCE TO START OF FLOWER INITIATION		2 1	1	2				
FLOWER INITIATION			2	3	2		1	
DATE OF MAXIMUM PRIMORDIUM NO. TO FLOWERING			3	3		3		
FLOWERING TO MATURITY				2		1	3	3
HARVEST							1	1

Since the components of grain yield (Table 11) are not independent of each other, high numbers of grains m^{-2} are often associated with low mean grain weights. Mean grain weight tends to be the least variable component especially when cultivar is removed as a source of variation. Six-row types have more grains ear^{-1} than two-row types and a correspondingly reduced number of ears m^{-2}.

TABLE 11. RANGE OF VALUES FOR COMPONENTS OF YIELD.

TYPE COMPONENT	WINTER 6-row	WINTER 2-row	SPRING 2-row
ears m^{-2}	270-670	500-880	540-1650
grains ear^{-1}	25-64	16-28	12-25
grains m^{-2} ($x10^{-3}$)	12-29	12-19	12-27
grain weight (mg)	34-49	33-56	25-46

6.2 Growth rate and harvest index

The effects of environment on growth rate depend mainly on its effect on canopy development (see section 6.5.2) since DMRQ is relatively constant except in conditions of severe water shortage (see section 6.1). Maximum short term growth rates (i.e. averaged over 7-14 d) of 36 g m^{-2} d^{-1} have been recorded for C_3 grasses corresponding to a mean global solar irradiation of 26 MJ m^{-2} d^{-1} but growing season averages fall to 13 g m^{-2} d^{-1} (Monteith, 1978).

The conventional definition of harvest index (HI) as the ratio of grain weight to total above ground weight at maturity has been used in this volume. All figures quoted in this section have been corrected to the same definition. HI is not the same as the ratio of grain weight to maximum biomass or total production because root weight, which is commonly 10% of the biomass at maturity, is excluded and because the above-ground biomass at harvest may be only 90% of the maximum because of respiration and loss of dead plant parts. Consequently grain yield is usually less than the product of total dry matter production and HI. Interpretation of figures in the literature is also complicated by differences in the methods employed such as the height at which the straw is cut. Both the mean and coefficient of variation (the standard deviation expressed as a percentage of the mean) are of interest and both appear to vary with cultivar and environment. Much of the increase in yield of modern barley varieties is due to increased HI. Riggs *et al.* (1981) grew a range of old and modern cultivars under the same conditions in the UK and found that mean HI ranged from 0.33 for cv. Chevallier, which was released in 1880, to 0.50 for cv. Triumph released one hundred years later. It has been suggested that as HI has increased it has become less variable presumably because the average is approaching the maximum possible HI of 0.60 suggested by Riggs (1984). Values of HI approaching 0.60 are likely to lead to unacceptable risks of lodging, poor light interception with a consequent reduced biomass at maturity and increased danger of infection by splash borne diseases so the HI of current cultivars may be close to the practical limit. Several authors have compiled tables from which the coefficient of variation can be derived. Gallagher & Biscoe (1978) reviewed UK trials on cv. Proctor (released in 1953) and obtained a coefficient of variation of 5% for a mean of 0.46. Biscoe & Willington (1984) used data from trials on several cultivars in the UK and found corresponding figures of 3% and 0.45. However, these values do not necessarily hold for all cultivars and environments. In some circumstances, although harvest index tends to be higher in dry years due to increased translocation of stored assimilates from the stem to sustain grainfill, other factors are a more important source of variation. Ilola *et al.* (1988) working in southern Finland found an average HI for Pomo spring barley of 0.52 for unirrigated and 0.48 for irrigated crops. The coefficient of variation was close to 10% in both cases. Shepherd *et al.* (1987) working with cv. Beecher in the contrasting Mediterranean climate of Syria found a much lower mean HI of 0.38 but the coefficient of variation was similar (11%).

Except in the more extreme environments, the harvest index of barley in the EC can therefore be taken to be 0.45. All the data discussed in this section refer to results from individual trials. At a regional scale the mean harvest index should be the same and the coefficient of variation is likely to be less.

6.3 Date of sowing

In most of Europe, autumn sowings are normally made in September or October and spring ones in March or April (Table 12). In Mediterranean regions, winter sowings (November and December) are normal. In many regions a wide range of sowing dates may be recorded. The date of sowing in each field depends on the suitability of the soil for cultivation (in north and west Europe not too wet and in the south and east not too dry), the date of harvest of the previous crop (for autumn sowings), the soil temperature (it should be above 5°C) and on the farmer's priorities for sowing. In spring, malting barley will have a higher priority than feed barley. There are parts of Europe where winter barley is sown as early as the middle of August and spring barley as late as the beginning of May without large losses of yield. Spring barley is sown as soon in spring as conditions are favourable. The French proverb 'à la Saint Georges (23 April) sème ton orge' indicates the latest date for sowing without loss of yield in the Bassin Parisien (R22) but most farmers will have finished sowing in the previous month. Winter sowings give a cycle length from sowing to harvest of about 250 days (range 160-330 d) and spring sowings 130 days (90-180 d).

TABLE 12. THE RANGE OF DATES OF SOWING, HEADING AND HARVEST CLASSIFIED BY AREA. DATES FOR AUTUMN OR WINTER AND SPRING SOWINGS ARE GIVEN SEPARATELY.

AREA	SOWING	HEADING	HARVEST
A	SEP I - JAN I	MAY I - JUN I	JUL I - AUG II
A	DEC I - MAY I	MAY II - JUL I	JUL II - NOV I
B	AUG II - OCT III	MAY II - JUN II	JUL II - AUG III
B	FEB II - MAY II	JUN II- AUG III	AUG I - NOV I
C	SEP I - JAN I	MAY I - JUN I	JUL I - AUG I
C	DEC I - MAY I	MAY II - JUL I	JUL I - SEP I
D	SEP I - SEP III	MAY II - JUN II	JUL I - AUG II
D	MAR I - APR III	JUN I - JUL I	JUL III - AUG III
E	AUG II - DEC I	APR II - MAY I	JUN II - JUL II
E	FEB I - MAY I	MAY II - JUN II	JUL II - SEP I
F	SEP II - NOV II	MAY I - JUN II	JUL I - AUG II
F	FEB II - MAY I	MAY III - JUL I	JUL III - SEP I
G	SEP I - OCT II	MAY I - JUN II	JUL - AUG I
G	MAR I - MAY I	MAY II - JUN III	JUL II - AUG II
H	AUG III - NOV III	MAY I - JUN I	JUL I - AUG I
H	DEC I - MAY I	MAY II - JUN III	JUL II - SEP I
I	SEP II - OCT III	MAR III - MAY III	JUN II - JUL II
I	FEB I - APR I	APR II - JUN I	JUL I - JUL III
J	SEP - OCT II	APR II - JUN I	JUN III - AUG I
J	FEB I - MAY I	MAY II - JUN III	JUL II - SEP II
K	AUG III - NOV I	APR II - JUN II	JUN II - AUG II
K	FEB II - MAY I	MAY II - JUL I	JUL II - AUG II
L	?-?	?-?	?-?
M	SEP II - NOV II	APR II - MAY III	JUN II - JUL III
M	FEB II - MAY I	MAY III - JUN III	JUL III - JUL I
N	OCT I - NOV I	APR I - APR III	JUN II - JUL I
N	JAN I - MAR I	APR II - JUN I	JUN III - JUL II
O	OCT I - DEC II	APR I - MAY II	JUN II - AUG II
O	DEC II - MAR II	MAY I - MAY III	JUN II - AUG II
P	SEP I - JAN II	MAR I - MAY II	MAY I - JUL III
Q	NOV II - FEB I	APR II - MAY II	JUN I - JUL II
R	OCT I - DEC III	APR III - MAY II	JUN I - JUL III
R	FEB I - MAR III	MAY I - MAY III	JUN III - JUL III
S	NOV I - NOV III	MAR II - MAY III	JUN II - JUL I
S	JAN I - FEB III	APR II - JUN I	JUN II - JUL II
T	OCT II - DEC II	APR I - MAY I	JUN I - JUN III
T	FEB I - MAR III	MAY II - MAY III	JUL I - AUG I

For the interpretation of satellite imagery, the key dates are not the absolute earliest and latest dates of sowing since in some parts of Europe barley could, at least in theory, be sown at any time of year. A more useful measure of the range is given by the dates which span the sowing dates of 90% of the barley area over a five year period. Barley sown outside these limits is likely to give very low yields. However, for modelling barley yield on a regional basis, the important measure of sowing date is the mean or median date. Very few estimates have been made of the mean date and those that have are almost certainly biased. In a five year survey of 223 fields of spring and 180 of winter barley in south-east Scotland (R7A1) the annual mean sowing date fell within a range of eight days for spring and eleven for winter barley compared with 70 and 123 days respectively for the ranges of dates for individual fields. No comparable data were found from other parts of the EC but these figures should be typical of North-west andCentral Europe.

6.4 SOWING TO EMERGENCE

Date of emergence can be defined in several ways. From a functional point of view the best definition is probably the date when 75% of the plants that are going to emerge actually have done so. In normal circumstances, there is only a delay of a few days between the emergence of the first and last plants. Meteorological factors affecting crop emergence are given in Table 13. There are two stages in this phase, germination and emergence. Germination is essentially the growth of the root and shoot region of the embryo at the expense of the food reserves in the endosperm. Barley seed begins to germinate at 2°C (Gate, 1989) and although the optimum is considered to lie between 15 and 20°C (Nuttonson, 1957) the time from sowing to emergence is independent of germination rate except in cold (less than 5°C) or very dry soils. Günter (1975) gives the duration of this phase as 10 d at an air temperature of 12°C and 20 d at 7°C and 15°C provided that water shortage does not limit development. Field experience suggests that these figures are an overestimate and that 14 d is a typical value. In controlled environment experiments at 20°C, Hao & de Jong (1988) found that emergence occurred within 4-6 d of sowing. In terms of thermal time, a typical value is 110°C d (base temperature 0°C) for cases where the soil temperature is below 12°C. One problem is that data are usually presented in terms of air temperature whereas the important variable is the mean 24 h soil temperature at the depth of the seed (about 30 mm). In the autumn, topsoil temperatures are generally greater than air temperature and the opposite is true of spring time. This would not be important if there were a constant relationship between air and soil temperature. However, there are significant differences in temperature regime between soils caused by variation in topsoil water content, which largely depends on topsoil texture. Emergence in autumn can occur 7 d earlier in fine soils than in coarse ones and the opposite holds in spring. Although the thermal time to emergence increases by 5°C d for every 10 mm increase in sowing depth (Gate, 1989) this source of variation is insignificant on a regional scale since the normal range of sowing depths is only from 10-30 mm. The effect of soil water status on time to emergence has been investigated by Hao & de Jong (1988). They found that neither the percentage of plants germinating nor the time to emergence was affected by soil water potentials below -0.5 MPa but that at potentials below -1.5 MPa emergence was severely impaired although the seed germinated. It is difficult to relate the soil water potential in the seedbed to soil water deficit since an increase in SWD of only a few mm may be sufficient to decrease the seedbed soil water potential below the threshold for emergence. In dryland agricultural systems of semi-arid regions, sowing takes place in the autumn or winter once 25 mm of rain have fallen at the start of the wet season as this has been found to be sufficient to allow reliable emergence. Poor emergence may also be due to pest attack, poor seed or saturation of the seedbed by water.

TABLE 13. METEOROLOGICAL FACTORS AFFECTING CROP EMERGENCE.

	SUB-OPTIMAL CONDITIONS		OPTIMAL CONDITIONS		SUPER OPTIMAL CONDITIONS	
	LOWER LIMIT	UPPER LIMIT	LOWER LIMIT	UPPER LIMIT	LOWER LIMIT	UPPER LIMIT
SOIL TEMPERATURE (°C)	2.0	6.9	7.0	15.0	15.1	?
ACCUMULATED SOLAR RADIATION (MJ m^{-2})	NA	NA	NA	NA	NA	NA
DAY LENGTH (h)	NA	NA	NA	NA	NA	NA
SOIL WATER STATUS	?	SWD>5	1<SWD<5		?	field capacity
TOTAL RAINFALL (mm)	?	?	5	20	?	?
MAXIMUM WIND SPEED (m s^{-1})	NA	NA	NA	NA	NA	NA
RELATIVE HUMIDITY (%)	NA	NA	NA	NA	NA	NA
LENGTH OF PHASE Calendar time Thermal time	RANGE 5 - 21 d 90 - 300°C d					MEAN 10 d 110°C d

6.5 EMERGENCE TO FLOWERING

6.5.1 *General features*

During this phase all the leaves appear, the stem apex switches from vegetative to reproductive development, the stem extends to its maximum extent and the ear develops. During the vegetative phase the sinks for assimilate are the leaves and the roots. After the onset of reproductive growth the stem also becomes a sink. The developing ear is a minor sink in terms of assimilate requirement since it makes up less than 5% of the total biomass at flowering. For satisfactory growth the average temperature during vegetative growth must exceed 9°C (Nuttonson, 1957). Meteorological factors affecting growth rate in this phase are given in Table 14.

6.5.2 *Leaf canopy development*

The number of mainstem leaves initiated before the onset of reproductive development varies with date of sowing (Fig.8) and cultivar. For an early autumn sowing there can be as many as 17 leaves (even more if vernalisation is incomplete) while for a late spring sowing there can be as few as seven. The points in Fig.8 are taken from a large number of trials mainly in the UK. Since photoperiod depends on latitude as well as on date, Fig.8 may not hold true for latitudes less than 50°N. The difference in leaf number between winter and spring types is due to the requirement of the former for vernalisation. However, the exact difference in leaf number between winter and spring types sown on the same day in the same location depends on genotype, environment and date of sowing. Note that in north-west Europe winter types are normally only sown in the autumn and spring types only in spring.

The thermal time between the appearance of successive leaves is called the phyllotherm and appears to be constant for each sowing date and location. Kirby, Appleyard & Fellowes (1982) and Ellis & Russell (1984) found that the rate of leaf appearance was related to the rate of change of daylength (astronomical daylength plus twice civil twilight) at crop emergence although it is not known whether this relationship is directly causal or whether it hides a more complex relationship with photoperiod. Taking both sets of data together the rate of leaf appearance was:

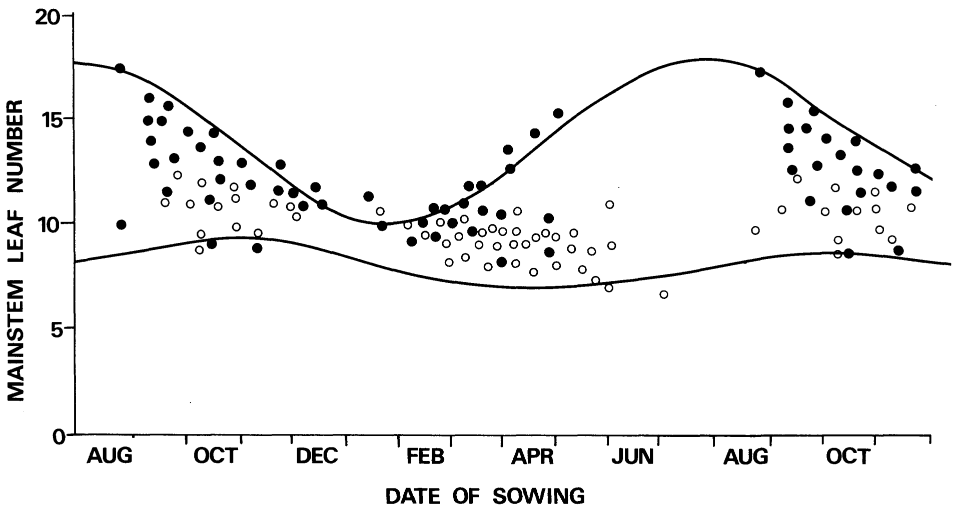
$$Y = 0.0131 + 0.05\ dL/dt$$

where Y is the rate of leaf appearance $(°C\ d)^{-1}$ and dL/dt is the rate of change of daylength in $h\ d^{-1}$.

TABLE 14. METEOROLOGICAL FACTORS AFFECTING GROWTH RATE.
i) CROP EMERGENCE TO HEAGING (GS 10-51).

	SUB-OPTIMAL CONDITIONS		OPTIMAL CONDITIONS		SUPER OPTIMAL CONDITIONS	
	LOWER LIMIT	UPPER LIMIT	LOWER LIMIT	UPPER LIMIT	LOWER LIMIT	UPPER LIMIT
AIR TEMPERATURE (°C)	2.0	8.9	9.0	25.0	25.1	35.0
ACCUMULATED SOLAR RADIATION ($MJ\ m^{-2}$)	350	899	900	NA	NA	NA
DAY LENGTH (h)	NA	NA	NA	NA	NA	NA
SWD/AWC	0.00	0.04	0.05	0.30	0.31	0.90
ACCUMULATED RAINFALL (mm)	250	?	?	?	?	1,000
MAXIMUM WIND SPEED ($m\ s^{-1}$)	0.0	1.0	1.1	25.0	25.1	30.0
RELATIVE HUMIDITY (%)	NA	NA	NA	NA	NA	NA
LENGTH OF PHASE	RANGE				MEAN	
Calendar time	55 - 230 d				?	
Thermal time	75 - 1,300°C d				?	

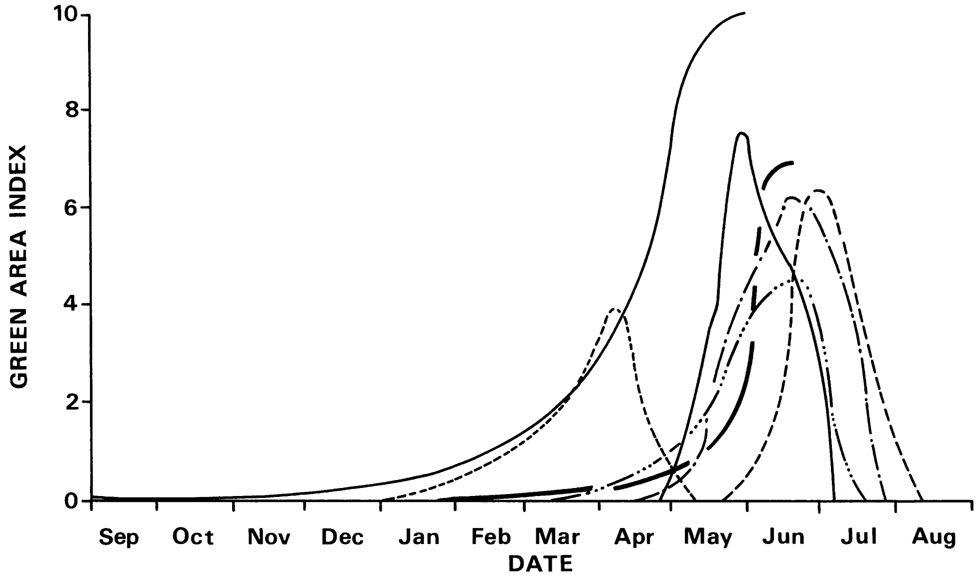
FIG. 8 THE FINAL NUMBER OF MAINSTEM LEAVES IN RELATION TO DATE OF SOWING. SPRING TYPES ARE DENOTED BY THE OPEN CIRCLES AND WINTER TYPES BY THE FILLED CIRCLES. THE EQUATION OF THE UPPER LINE IS N = 14 + 4 SIN [(n-22) x 0.986] AND OF THE LOWER N = 8.5 +SIN [(n-205) x 0.986] WHERE n IS THE DAY NUMBER AND THE ANGLE IS MEASURED IN DEGREES.



For the purpose of modelling barley growth, the key canopy attribute is the green area index (GAI) defined as the total area of the green parts of the leaves (one side only) plus the longitudinal sectional area of the green parts of the leaf sheaths divided by the ground surface area on which the plants stand. Some authors use leaf area index and ignore the sheath area although the latter is a significant part of the total once stem extension has started. The GAI depends on the rates of leaf emergence, both on the mainstem and on the tillers, expansion and senescence. After emergence, GAI increases exponentially then passes through a linear phase before reaching a maximum and then declining. Cooper, Keatinge & Hughes (1983) found that peak GAI in the semi-arid climate of northern Syria occurred close to the time of anthesis while Russell & Ellis (1988) found that GAI peaked 200°C d before anthesis in the wetter conditions of south east Scotland. It might have been expected that GAI should peak earlier in the dry climate due to the earlier onset of senescence. The discrepancy may be partly due to the cultivars involved. The time course of GAI is shown in Fig.9 for a selection of experiments from Finland in the north to Syria in the south and including a wide range of sowing dates and soil water régimes. There is considerable variation as might be expected, most of which is due to the timing of the growth cycle. It should be noted that GAI was always less than 1.00 between August 10 and January 31. GAI values of 10.0 have been recorded in

North-west Europe but 6.5 is more typical. There is a theoretical upper limit because the lower leaves die when the irradiance is insufficient to support them (Monteith & Elston, 1983) and normally only four leaves survive on each stem. Although the maximum should thus vary with radiation climate, regions with high solar radiation tend also to be dry so less leaf area is produced and the maximum is correspondingly reduced. Lax-leaved cultivars should be able to support a lower GAI than erect-leaved types due to the pattern of radiation transmission but this effect will be much less than the environmental ones discussed already.

FIG. 9 THE TIME COURSE OF GREEN AREA INDEX. EACH LINE REPRESENTS A SINGLE EXPERIMENTAL TREATMENT.

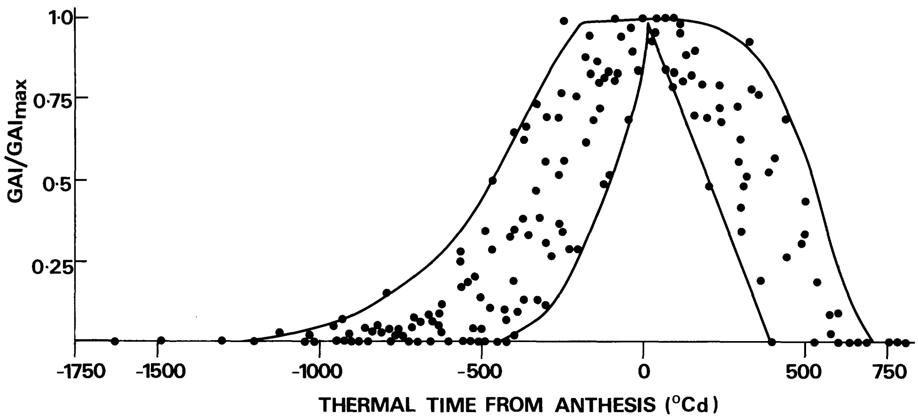


No definitive predictive model of barley GAI applicable to all parts of the EC has yet been produced. Three approaches to the problem have been tried. The demographic method describes GAI in terms of the number of leaves developing and their rate of expansion. Porter (1984) developed a model of this type for wheat which could be modified for barley. The second method partitions assimilate to leaf expansion according to rules incorporating environmental factors and an assumed value of specific leaf area. Van Keulen (1986) suggests a default value of 25 $m^2 kg^{-1}$ for barley but large errors can be introduced if the effects of environment and ontogeny on SLA are ignored. Russell (1988) showed that at a GAI of 4.0 the above-ground crop biomass can vary within a range of $\pm$40%. The third method is to calculate GAI as a function of thermal time, taking account of the variation in thermal time from crop emergence to anthesis. Uhlehla (1981) was able to explain 80% of the variation in the time course of GAI in terms of temperature alone. Baret (1986) developed a model for wheat in which leaf biomass (GAI = leaf biomass x SLA) was estimated as the sum of a logistic and an exponential decay function of thermal time and which gave good agreement with experimental results. These relationships hold because the rates of initiation, appearance and expansion of leaves are strongly dependent on temperature (Monteith & Elston, 1983) while a reserve of assimilates is normally sufficient to allow leaf growth of grasses such as barley even in unfavourable conditions of light (Gillet, Lemaire & Gosse, 1984). A temperature based model of GAI such as that of Baret could be modified to take account of long periods of very high or low irradiation by setting phenologically variable upper and lower limits to leaf area ratio (leaf and sheath area divided by crop biomass). Shortage of nitrogen and water limit the development of GAI both by reducing the rate of expansion of new leaves and by increasing the rate of senescence of old ones.

Data from 18 location-year-cultivar trial combinations (Aslyng & Hansen, 1982; Biscoe, Scott & Monteith, 1975; Bragg *et al.*, 1984; Cooper, Keatinge & Hughes, 1983; Grant, 1984; Ilola, Elomaa & Pulli, 1988; Leach, 1980; Russell *et al.*, 1982;), including those from Fig.9, were analysed to examine the relationship between GAI and thermal time in more detail (Fig.10). Complete information was not always given and estimates, especially of temperature, had to be made. GAI was normalised to the maximum achieved in each trial treatment in an attempt to remove the effect of shortage of water on maximum GAI. The abscissa is thermal time before or after anthesis rather than from sowing to reduce the differences between spring and winter types. An alternative procedure of setting the thermal time from emergence to anthesis as 1.00 was found to be less successful. The scatter of points in Fig.9 has been reduced but considerable variation is still unaccounted for. The range of approximately 400°C d for any value of GAI/GAI_{max} is equivalent to three decades at a mean 24 h temperature of 13°C. Some of the variation is attributable to date of sowing with autumn sowings of winter barley tending to give points near the outside of the rising curve and some to inaccurate estimates of thermal time

The effect of soil water status on the rate of increase of GAI is shown in Fig.7. The points have been derived from data in Day *et al.* (1978) describing the results of an experiment with a range of contrasting water régimes. Leaf area expansion is inhibited at much lower soil water deficits than is DMRQ (Fig.7) due to the effect of water supply on the rate of cell expansion. When rain falls after severe water stress has occurred for a period of weeks, the increase of GAI can exceed the potential rate (when the SWD is zero) as cells which have divided but been unable to expand suddenly enlarge. In this context, soil water deficit should be considered to be zero after rainfall until all the rain has been evaporated even thought there is still a positive profile SWD (Gardner, 1981).

FIG. 10 THE TIME COURSE OF NORMALISED GREEN AREA INDEX. THE ORDINATE IS THE RATIO OF ACTUAL TO MAXIMUM GAI AND THE ABSCISSA IS THE THERMAL TIME FROM ANTHESIS.

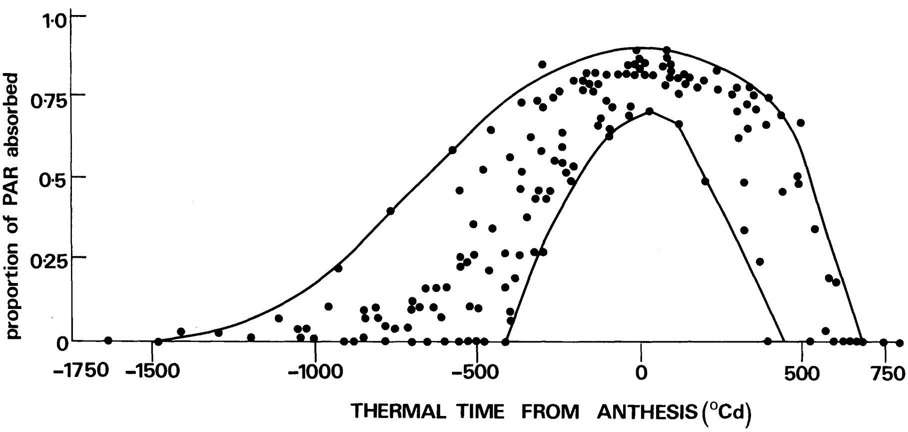


The relationship between GAI (G) and the proportional absorption of PAR (F) is given by an asymptotic curve (Gallagher & Biscoe, 1978):

$$F = (1 - \exp(-0.9\, k\, G))(1 - a)$$

where k is a light extinction coefficient taken as 0.44 for temperate cereals (Monteith, 1973) and a is a reflection coefficient which is 0.10 for the waveband 400-700 nm. About 80% of the incident PAR is absorbed by a crop canopy when GAI reaches 3.0 and the maximum absorption is 0.90 to account for radiation reflected from the top of the canopy. The data in Fig.10 were recalculated to give percentage absorption of PAR on the ordinate (Fig.11) and this has the effect of expanding the lower part of the curve and contracting the upper with the result that the relationship becomes rather poor. The relationship between radiation interception and foliage cover has been treated experimentally and theoretically by Steven *et al.* (1986). Although the proportional absorption of PAR by barley has been modelled as a function of thermal time directly (Russell & Ellis, 1988) it is then difficult to include the effects of drought, disease or disease which act on GAI.

FIG. 11 THE TIME COURSE OF PAR ABSORPTION BY BARLEY CANOPIES.

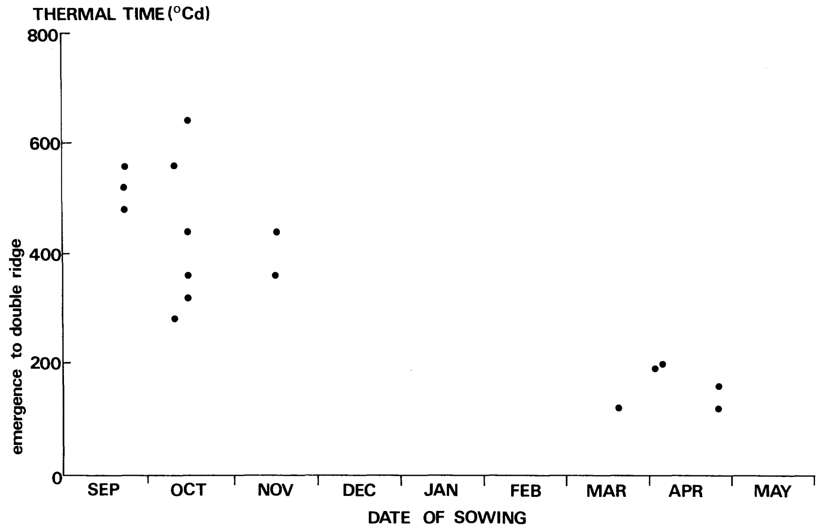


6.5.3 *Emergence to floral initiation*

Before the four leaf stage (GS 14), air temperatures below -8°C can kill barley plants (Gate, 1989). After this stage the sensitivity to cold depends on the state of hardening of the plant (see also section 3.2). Hardening of the plant tissues is a reversible biochemical process which occurs in response to exposure to a period of cool weather and which confers resistance to cold.

Important changes occur on the stem apex during this phase. Three to four leaf primordia have already been initiated on the stem apex in the embryo by the time of germination. A further four to twelve are initiated in sequence before the collar at the base of the incipient ear is formed which is itself followed by ten to forty-five spikelet primordia (Wych, Simmons, Warner & Kirby, 1985). Initially all primordia are undifferentiated and cannot easily be distinguished morphologically. However, the transition to reproductive growth is marked by a pronounced increase in the rate of primordium initiation. The first morphological sign of reproductive development is the appearance of double ridges on the younger spikelet primordia. Although this stage of development is often referred to as 'floral initiation' it occurs after ten to twenty spikelet primordia have already been initiated. In winter types, initiation takes place in response to vernalisation and photoperiod and occurs later on the tillers than on the mainstem. In spring types initiation occurs almost synchronously on the mainstem and tillers after seven to ten leaves have been initiated on the mainstem (Fig.8).

FIG. 12 THERMAL TIME FROM CROP EMERGENCE TO THE DOUBLE RIDGE STAGE OF APICAL DEVELOPMENT.



Data on the duration, in thermal time, of this and succeeding phases have been taken from an unpublished review by GW Wilson of a large number of trials, mainly in the UK. The thermal time from crop emergence to double ridge formation declines with date of sowing (Fig.12). Some of the variation for autumn sowings must be due to time of vernalisation. The primordium which will ultimately develop into the collar at the base of the ear is initiated before double ridges are first observed. This delay is 350°C d for September sowings in the UK and 50°C d for sowings after mid November (GW Wilson pers. comm.)

The problem of predicting the transition from vegetative to reproductive development on the stem apex has not yet been solved completely although there is now a considerable literature. The first morphological indication is the appearance of double ridges on the upper (i.e. spikelet) primordia but the transition can be identified by an increase in the rate of initiation of primordia (Wright & Hughes, 1987) which occurs a few days earlier. In some experiments with spring cultivars (Wright & Hughes, 1987) flag leaf initiation, and thus the start of reproductive development, occurs within a week of crop emergence. Consequently, the photoperiodic cue must be detected within this period. Photoperiod at crop emergence has been shown to affect the rate of leaf initiation (section 6.5.2) and this clearly has an effect on the date when reproductive development starts. However, there may be a secondary effect on the number of leaves produced. Winter barleys must be vernalised before full reproductive development can occur. Although unvernalised plants will flower late and sporadically in response to lengthening photoperiods this is of no practical significance. Vernalisation is accomplished by the exposure of the plants, or the imbibed seeds, to temperatures between 0°C and 12°C for a period of weeks depending on the actual temperatures experienced and the cultivar. Petr (1988) suggested that 22-24 days of exposure to vernalising temperatures was sufficient for winter barley growing in photoperiods longer than 12 h. Temperatures between 4°C and 8°C are most effective for vernalisation. Interestingly, Russell & Ellis (1988) found that autumn-sown spring types did not reach anthesis before winter types sown on the same date suggesting that the requirement for vernalisation was not a limiting factor for rate of development. It is not known how widespread this phenomenon is. Although physiologists normally talk about the triggering of reproductive growth as if the vegetative phase were the norm, the converse position is perhaps more useful (R F Lyndon pers.comm.) From this viewpoint, the question should be why the vegetative phase is so prolonged: vernalisation can then be seen as a mechanism for delaying the transition to reproductive development till a time of year when conditions are less severe.

Roberts *et al.* (1988) have carried out a comprehensive set of growth room experiments into the effect of photoperiod on a wide range of barley cultivars taking time to awn appearance (GS 49) as their measure of development rate. They found that they could define a critical photoperiod of 13-16 h above which the rate of development was independent of photoperiod. Stewart & Dwyer (1987) found a similar figure. There was also a photoperiod of about 10 h below which there was no further slowing of the rate of development. It is important, especially for higher latitudes, to establish the period during which barley plants respond to photoperiod so that an appropriate average figure can be calculated. Roberts *et al.* (1988) discovered that there was a pre-inductive phase for 8-10 d after germination when spring and vernalised winter barleys did not respond to photoperiod. The inductive phase therefore starts at approximately crop emergence for these types. In unvernalised plants the pre-inductive phase lasted more than a month and it is tempting to suggest that it ended shortly after vernalisation was complete. Russell *et al.* (1982) found that the rate of leaf appearance was directly related to the photoperiod at coleoptile emergence (approximately crop emergence) so that the thermal time till heading, which can be thought of as the product of the rate of leaf appearance and the number of leaves, should be unresponsive to photoperiod once floral initiation has started. However, Roberts *et al.* (1988) found that changing the photoperiod at any time during the entire period up till the end of spikelet initiation (MPN) influenced the time to heading. The mechanism involved is unclear.

The transition to reproductive development can be modelled in three ways. Firstly as the product of leaf number and phyllotherm. This method will work well if the mean number of leaves is well correlated with sowing date and geographical location. The second way is to use photoperiod to weight thermal time and thus derive a photothermal time (Baker & Gallagher, 1983; Nuttonson, 1957). Implicit in this concept is the idea that photoperiod affects development equally throughout the development phase of interest. Ellis *et al.* (1988) used a similar concept when they predicted the duration of the period from sowing to awn emergence (f) as:

$$1 / f = a + b T + c P$$

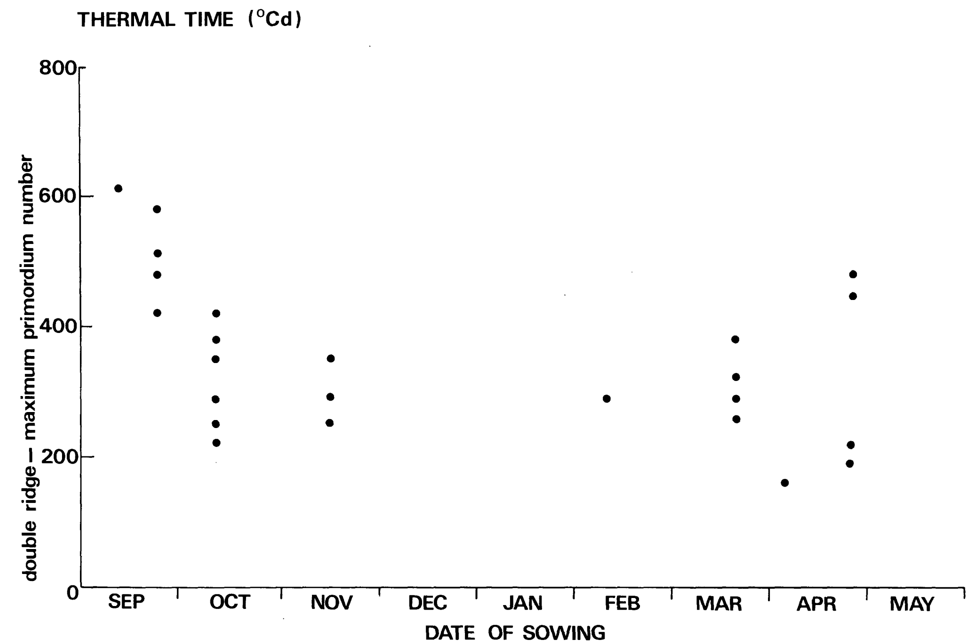
Since T is the mean temperature, the product of f and T approximates to thermal time. The appropriate value of P, the photoperiod for field grown crops, is unclear. The third way of predicting the onset of reproductive growth is to use a set of rules of the form: transition <u>if</u> thermal time from sowing is x °C <u>and</u> the crop has been vernalised, where x is a function of photoperiod.

Barley tillers are produced in a characteristic sequence. A single tiller bud is already present in the embryo at germination. A bud develops in the axil of the coleoptile and each of the lower leaves of the plant. Since tillers can also form in the axils of the lower leaves of primary tillers the total number of tillers is potentially large. The proportion of buds which actually develop into tillers depends on genotype and environment, particularly irradiance and nitrogen status. The first tiller is almost as large as the mainstem but other tillers are progressively smaller. Since tillers produce fewer leaves than the mainstems, ear emergence takes place almost synchronously over the whole population of stems (Kirby & Appleyard, 1984). Tillering starts after the appearance of the fourth leaf, which typically occurs 10-15 days after emergence in spring sown barleys but which could occur more than 150 days after emergence in winter barleys sown in late autumn.

6.5.4 *Floral initiation to stem extension*

Vegetative and reproductive growth proceed till new primordia cease to be initiated. Unlike wheat, no terminal spikelet is formed but the analogous stage of maximum primordium number (MPN) occurs when primordium death starts to occur at the tip of the developing ear. The stem internodes begin to elongate almost at the same time as MPN is achieved. The thermal time from DR to MPN is about 250°C d (Fig.13) and appears to be independent of sowing date. Part of the variation may be due to the choice of 0°C as base temperature since some researchers consider that the base temperature is higher during the reproductive phase.

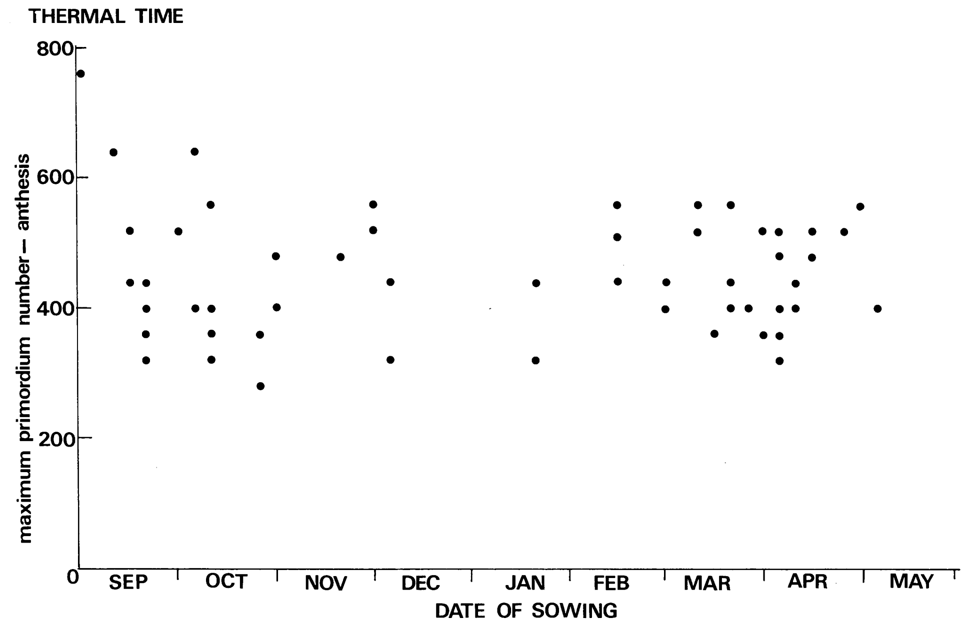
FIG. 13 THERMAL TIME FROM THE DOUBLE RIDGE TO THE MAXIMUM PRIMORDIUM NUMBER STAGES OF APICAL DEVELOPMENT AS A FUNCTION OF DATE OF SOWING.



6.5.5 *Stem extension to flowering*

This phase occurs immediately after the 'ear at 1 cm' stage of the French agronomists (Couvreur *et al.*, 1980). During the phase, the spikelet number declines till the final number of grains per ear is reached at ear emergence. Stem extension occurs due to the elongation of the upper five or six internodes of the stem. Plant height can be defined as the distance from ground level to the collar at the base of the ear or to the ligule of the uppermost leaf. Whatever the definition, the final height can range from 0.50 m for short strawed cultivars growing in dry conditions to 1.50 m for long strawed cultivars freely supplied with water. Thermal time from MPN to anthesis is approximately 450°C d (Fig.14). After MPN the crop becomes sensitive to cold once more and the developing ear can be damaged by air temperatures below -6°C (Massé & Orsini, 1989). In the week preceding anthesis exposure to temperatures below 5°C can disrupt the process of meiosis and reduce the proportion of pollen that is fertile (Gate, 1989).

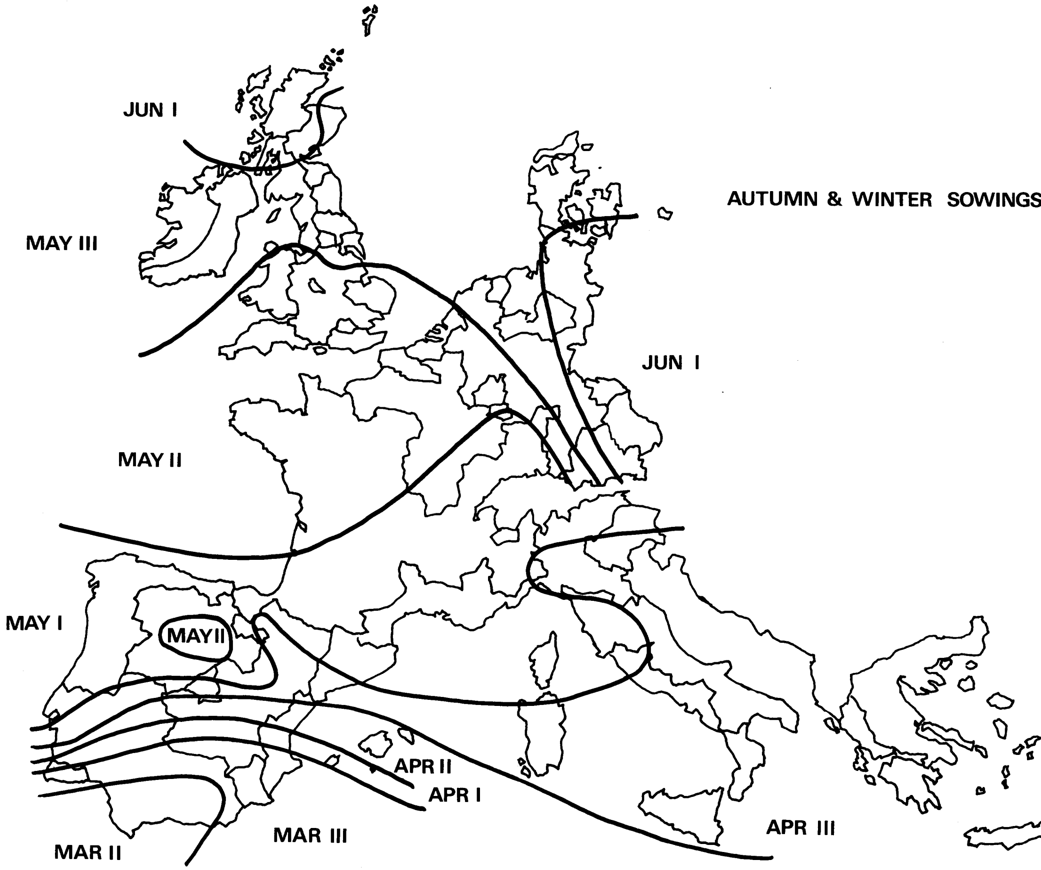
FIG. 14 THERMAL TIME FROM THE MAXIMUM PRIMORDIUM NUMBER STAGE OF APICAL DEVELOPMENT TO ANTHESIS AS A FUNCTION OF DATE OF SOWING.

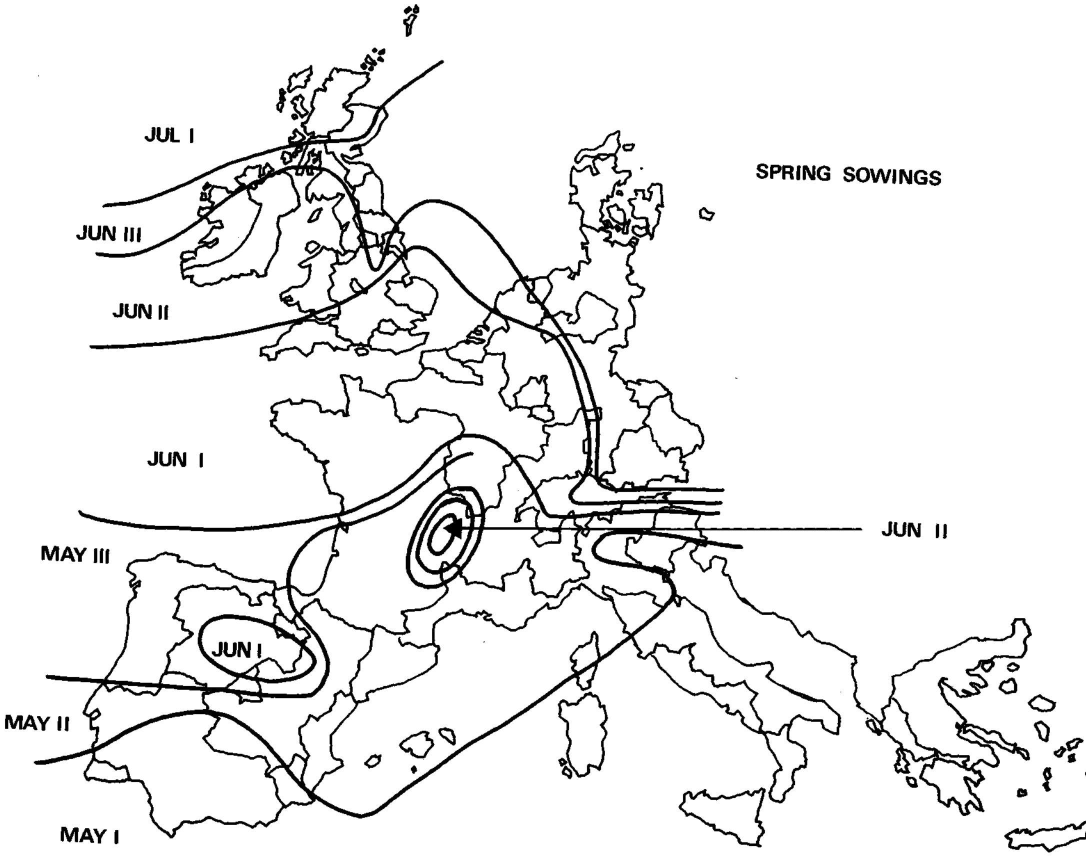


6.6 Flowering to physiological maturity

Flowering (anthesis), that is when the anthers dehisce and shed pollen onto the receptive stigmas of the carpel, is a key stage in the development of the cereals. However, from the point of view of general agronomic research and especially in connection with remote sensing work, the related date of ear emergence (heading) is more useful. Ear emergence normally occurs within a few days of anthesis, the precise difference depending on the cultivar. The mean date of heading averaged over a five year period ranges from the second decade in March for winter sowings in southern Spain to the first decade in July for late spring sowings in northern Scotland (Fig.15; Table 12). Variation in date of heading within regions is due both to date of sowing and to the temperature régime at particular sites. A more accurate estimate of the mean regional date of anthesis could be obtained by using satellite imagery to find the mean date of ear emergence over a period of five years. As a first approximation the date of anthesis in any year could then be predicted using empirical relationships between temperature and deviation from the mean date of anthesis.

FIG. 15 MEAN DATE OF BARLEY EAR EMERGENCE IN THE EC.




SPRING SOWINGS
JUL I
JUN III
JUN II
JUN I
MAY III
JUN I
MAY II
MAY I
JUN II

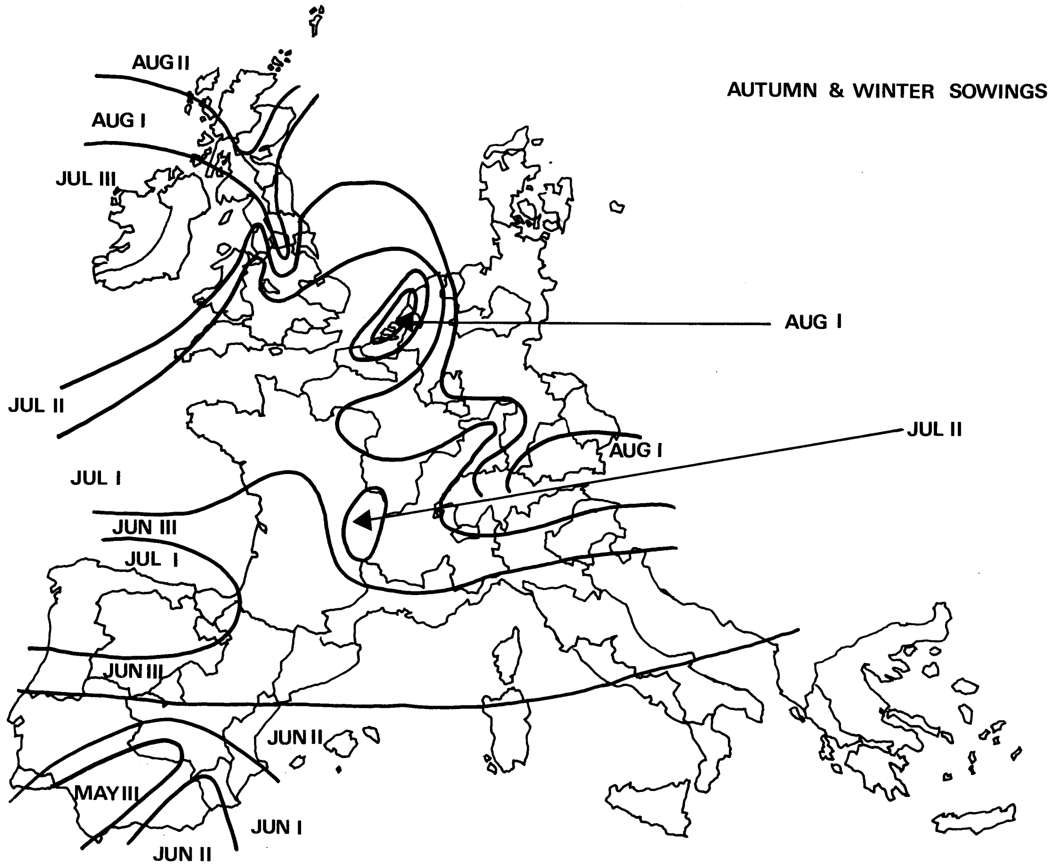
All current barley cultivars are self-fertile with fertilisation occurring immediately after the anthers mature although cross pollination does occur in open flowering types (see below), particularly in six-row winter cultivars. This is occasionally a problem in seed crops. On the other hand, cross pollination can be beneficial when pollen is damaged by exposure to low temperatures during meiosis (Gate, 1989) although it will only be successful if the weather is dry so that the pollen can be transported by the wind in the short period during which the florets are receptive. There are two types of flowering, open and closed. Most spring and some winter varieties are closed flowering, that is the anthers are not visible externally till well after anthesis. Open flowering varieties are like wheat where the date of anthesis is the date when the anthers are visible at externally. In closed flowering types, the date of anthesis can be found by dissection or estimated as a number of days before or after ear emergence, the exact correction depending on cultivar. Flowering proceeds almost simultaneously across the field. In most spring barleys flowering takes place immediately before heading before the spike has fully emerged from the boot. Flowering of winter barleys is normally a few days after ear emergence. Consequently, the exact relationship between the dates of heading and anthesis depends primarily on cultivar. Normally most of the flowers present at anthesis are pollinated and survive to produce grain. Although temperature extremes, low relative humidity and copper deficiency can all provoke floret sterility, the effect on yield at a regional level is considered to be insignificant.

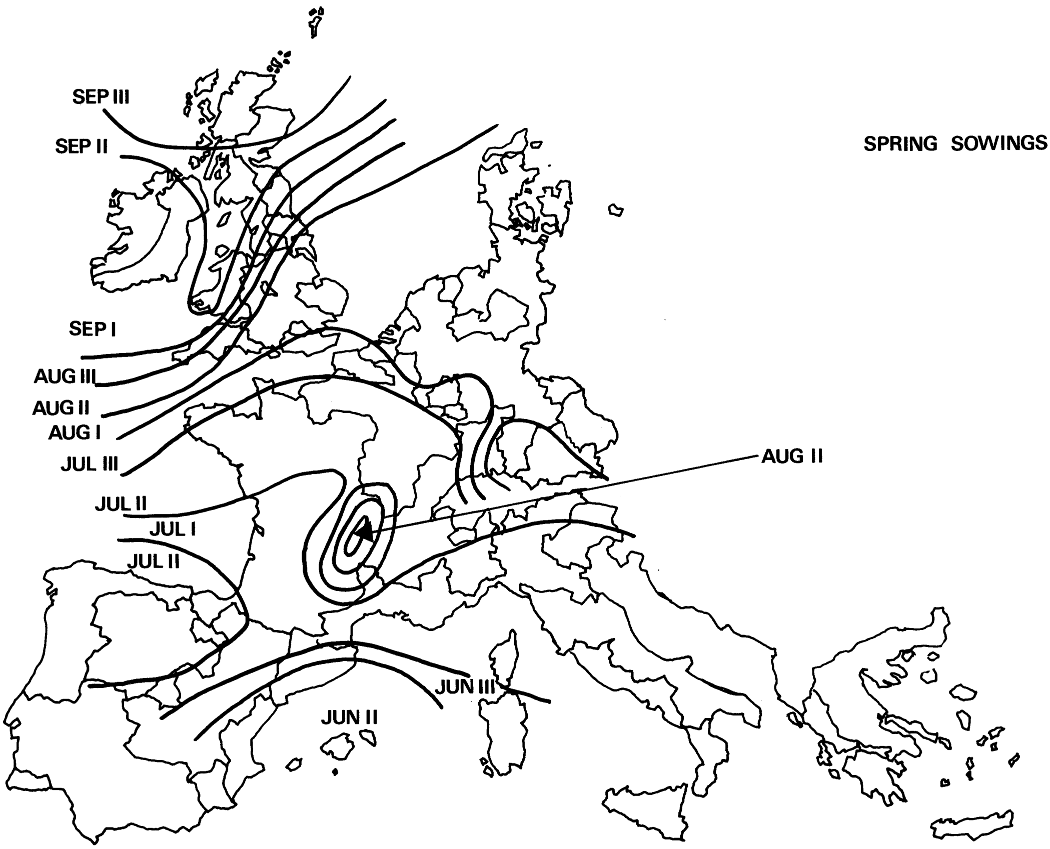
Meteorological factors affecting growth rate during the grainfill period are given in Table 15. Grain formation occurs in three stages: the milk stage which ends about 350°Cd after anthesis, the dough stage, which lasts a further 200°Cd, and a ripening phase. After anthesis, the grain begins to fill and passes through a regular progression of stages from milk to dough as the endosperm starch is laid down. The milky ripe stage generally begins 12-15 days after fertilisation. During this time there is a progressive senescence of the leaves followed by the awns and glumes of the ear. Grain dry weight reaches a maximum at the end of the dough stage, 30-50 days after anthesis. Temperatures above 30°C during grainfill may adversely affect development of the grain (Hough, 1975) but temperatures as high as 40°C appear to be less injurious to barley than to wheat and oats (Nuttonson, 1957). Water shortage during the first half of grain fill can lead to the production of small grains and an increased proportion of shrivelled grains and screenings. Aspinall (1965) investigated the effect of soil water stress on grain fill in controlled environment studies. He found that when water stress was not severe, duration of grainfill was more affected than the rate of grainfill. When severe drought treatments (soil water potentials below -1.5 MPa) were imposed after anthesis the duration of grain fill was reduced to 80% of a well-watered control and the rate of grainfill to 75%.

TABLE 15. METEOROLOGICAL FACTORS AFFECTING GROWTHRATE. ii) HEADING - MATURITY (GS 51 - 93).

	SUB-OPTIMAL CONDITIONS LOWER LIMIT	SUB-OPTIMAL CONDITIONS UPPER LIMIT	OPTIMAL CONDITIONS LOWER LIMIT	OPTIMAL CONDITIONS UPPER LIMIT	SUPER OPTIMAL CONDITIONS LOWER LIMIT	SUPER OPTIMAL CONDITIONS UPPER LIMIT
AIR TEMPERATURE	8.0	14.9	15.0	25.0	25.1	35.0
ACCUMULATED SOLAR RADIATION ($MJ\ m^{-2}$)	350	699	70	NA	NA	NA
DAY LENGTH (h)	NA	NA	NA	NA	NA	NA
SOIL WATER DEFICIT/ AVAILABLE WATER CAPACITY	0.00	0.04	0.05	0.40	0.41	0.90
ACCUMULATED RAINFALL (mm)	0	29	30	59	60	200
MAXIMUM WIND SPEED ($m\ s^{-1}$)	0.0	0.9	1.0	1.49	15.0	20.0
RELATIVE HUMIDITY (%)	NA	NA	NA	NA	NA	NA
LENGTH OF PHASE	RANGE				MEAN	
Calendar time	30-70 d				50 d	
Thermal time	750 - 900°C d				850°C d	

FIG. 16 MEAN DATE OF BARLEY HARVEST IN THE EC.




SEP III
SEP II
SEP I
AUG III
AUG II
AUG I
JUL III
JUL II
JUL I
JUL II
AUG II
JUN III
JUN II
SPRING SOWINGS

6.7 Physiological maturity to harvest

Once maximum dry weight is reached the predominant process is physical drying (ripening). The final phase of ripening is not driven by the processes controlling evaporation from a free water surface but by the equilibration of the osmotic potential of the grain with the relative humidity of the atmosphere. Mean dates of harvest are given in Fig.16 and Table 12. The range of dates encountered increases as harvest becomes later and the climate becomes less favourable.6.8 Post-harvest

6.8 Post-Harvest

Not all the grain in a field is actually harvested although losses in good conditions are normally less than 5%. Further losses occur if the proportion of small grains is large. Losses can also occur from pest attack and deterioration of inadequately dried grain during storage and transport but again the average losses are relatively low. Dormancy is normally lost within a few days of harvest but the longer periods typical of some cultivars rarely cause problems.

7. METEOROLOGICAL FACTORS AFFECTING FIELD OPERATIONS

7.1 Field preparation

The conditions for successful ploughing are given in Table 16. The possible soil moisture conditions for ploughing are given in terms of field capacity. However, the critical factor is whether the soil is below, that is drier than, the lower plastic limit. For many but not all soils the lower plastic limit occurs close to field capacity. With spring-sown crops, sowing is unlikely to be delayed by ploughing since it generally takes place well before sowing. Indeed, ploughing is not always necessary (see section 4.2.2).

TABLE 16. METEOROLOGICAL FACTORS AFFECTING FIELD ACTIVITIES - PLOUGHING.

	SUB-OPTIMAL CONDITIONS LOWER LIMIT	SUB-OPTIMAL CONDITIONS UPPER LIMIT	OPTIMAL CONDITIONS	SUPER-OPTIMAL CONDITIONS LOWER LIMIT	SUPER-OPTIMAL CONDITIONS UPPER LIMIT
DATE, PERIOD			see text		
MAXIMUM TEMPERATURE (°C)	NA	NA	0-10	10.1	ND
SOIL MOISTURE STATUS (Moisture content as % by volume in topsoil)	NA	NA	7% (coarse) 15% (medium & MF) 25% (fine & VF) to field capacity	field capacity	105% of field capacity
GENERAL WEATHER CONDITIONS	NA	NA	In Mediterranean region 10 days after after autumn rains	NA	NA

DURATION OF THE ACTIVITY (d)	Range	Mean
Per field	1 - 10	5
Per region	?	30(w)90(s)

M.F. = Medium fine; V.F. = Very fine
w = autumn or winter sowing; s = spring sowing

7.2 Establishment

The processes of cultivation, sowing and seedbed fertiliser application have been treated together (Table 17) since the same environmental factors act on all of them and they commonly take place one after the other. Indeed it is possible for all three to take place in the same field in the course of a day.

TABLE 17. METEOROLOGICAL FACTORS AFFECTING FIELD ACTIVITIES - CULTIVATION, SOWING AND SEEDBED FERTILISER APPLICATION.

	SUB-OPTIMAL CONDITIONS LOWER LIMIT	SUB-OPTIMAL CONDITIONS UPPER LIMIT	OPTIMAL CONDITIONS	SUPER-OPTIMAL CONDITIONS LOWER LIMIT	SUPER-OPTIMAL CONDITIONS UPPER LIMIT
DATE, PERIOD			see text		
TEMPERATURE (°C)	5	7	7.1 - 20	20.1	30
RAINFALL (mm)	NA	NA	0	0.1	1
SOIL MOISTURE STATUS	NA	NA	< 95% field capacity	95% field capacity	field capacity
GENERAL WEATHER CONDITIONS	NA	NA	NA	NA	NA
DURATION OF THE ACTIVITY (d)	Range			Mean	
Per field	1 - 10			5	
Per region	ND			ND	

7.3 Fertiliser application

With spring barley, all of the nitrogen, potassium and phosphorus fertiliser may be applied in the seedbed. However, with autumn-sown crops application of nitrogen in spring is of great importance. For maximum effect the top dressing should be applied after the soil temperature has passed 5°C but before the second node has appeared on the stem (Table 18). However, this simple picture is complicated because of the danger of leaching if heavy rains fall when the soil is near field capacity (the state of a freely drained soil after excess water has drained away following complete re-wetting of the profile) and the risk of low uptake if the soil is dry. For these reasons the top dressing may be split into two or three applications.

TABLE 18. METEOROLOGICAL FACTORS AFFECTING FIELD ACTIVITIES - TOP DRESSING WITH NITROGEN FERTILISER.

	SUB-OPTIMAL CONDITIONS LOWER LIMIT	SUB-OPTIMAL CONDITIONS UPPER LIMIT	OPTIMAL CONDITIONS	SUPER-OPTIMAL CONDITIONS LOWER LIMIT	SUPER-OPTIMAL CONDITIONS UPPER LIMIT
DATE, PERIOD	Jan 15	Jan 31	Feb 1 - Mar 31	Apr 1	May 31
PHENOLOGICAL STAGE (ZADOKS)	21	25	26 - 30	31	32
MAXIMUM TEMPERATURE (°C)	NA	NA	5 - 20	20.1	40
RAINFALL (mm)	NA	NA	0 - 2	NA	NA
SOIL MOISTURE STATUS SOIL WATER DEFICIT (mm)	0	10	10.1 - 20	20.1	100
GENERAL WEATHER CONDITIONS	NA	NS	5 mm rain after application	NA	NA
DURATION OF THE ACTIVITY (d)	Range			Mean	
Per field	1			5	
Per region	ND			ND	

7.4 CHEMICAL SPRAYS

Chemical sprays can be applied to control weeds, pests or diseases or as growth regulators (eg straw stiffeners or shorteners). Most weeds, pests and diseases can now be controlled chemically although this may not be the preferred option. General conditions necessary for successful spraying are given in Table 19 although the optimum growth stage varies with the chemical applied. Technological solutions such as aerial spraying or the use of low ground pressure vehicles can extend the period when spraying is possible into those times of year when the soil is too wet for normal application.

TABLE 19. METEOROLOGICAL FACTORS AFFECTING FIELD ACTIVITIES - HERBICIDE AND FUNGICIDE APPLICATIONS.

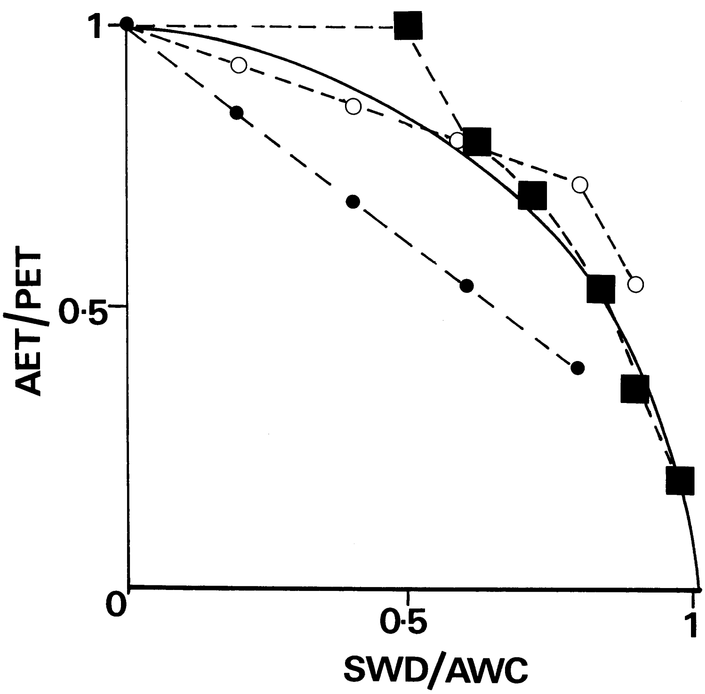
	SUB-OPTIMAL CONDITIONS LOWER LIMIT	SUB-OPTIMAL CONDITIONS UPPER LIMIT	OPTIMAL CONDITIONS	SUPER-OPTIMAL CONDITIONS LOWER LIMIT	SUPER-OPTIMAL CONDITIONS UPPER LIMIT
DATE, PERIOD	RR	RR	RR	RR	RR
PHENOLOGICAL STAGE	NA	NA	NA	NA	NA
TEMPERATURE (°C)	8	10	10.1 - 20	20	
SOIL MOISTURE STATUS (mm)	Field capacity	10	Soil water deficit >10	?	?
GENERAL WEATHER CONDITIONS	NA	NA	No rain in following week	NA	NA
10 m WINDSPEED (ms^{-1})	NA	NA	2 - 10	NA	NA

7.5 Irrigation

Irrigation of barley is uncommon in most of the EC (see section 4.6). Where it is considered worthwhile and the water is available, the amount and timing of irrigation will depend on the stage of development of the crop (see section 4.6) and the soil water deficit. The potential rate of evaporation (ie including transpiration) can be calculated from the Penman-Monteith equation (Monteith, 1965) using a minimum value for the surface resistance (r_s) of 30 s m^{-1} (Grant, 1975; Russell, 1980) between canopy closure and ear emergence. This value is likely to increase with the rise in atmospheric CO_2 concentration. Russell (1980) showed that r_s remained close to its minimum value till approximately 30% of the available water in the soil profile had been used up.

The ratio of actual to potential evaporation, where the potential is defined as the rate of evaporation when the soil is at field capacity, was plotted against the ratio of SWD to AWC (Fig.17) for three sites for which data were available (Day *et al.*, 1978; Russell, 1980). The ratio declines to 0.80 when 60% of the available water has been removed. A model for estimating soil water deficits under cereal crops based on the Penman equation has been developed for UK conditions (Francis & Pigeon, 1982a,b) but should be capable of modification for other climatic regions although the time course of canopy development is not calculated but has to be specified.

FIG. 17 THE RATIO OF ACTUAL TO POTENTIAL EVAPOTRANSPIRATION AS A FUNCTION OF THE RATIO OF SOIL WATER DEFICIT TO AVAILABLE WATER CAPACITY. THE SYMBOLS REPRESENT THREE DIFFERENT SOIL TYPES.



7.6 HARVEST

Meteorological factors affecting harvest are given in Table 20. Ideally the crop would be harvested at GS 93 and a moisture content of 15%. Although harvesting can take place at 31% MC (Philips & O'Callaghan, 1974), 20% is a more realistic upper limit. In the drier parts of Europe this does not pose problems but elsewhere there are risks of major losses due to wind or rain if harvest is delayed till the optimum conditions are achieved. In such regions grain may be routinely harvested at 20% MC and dried artificially. McGechan *et al.* (1989) have evaluated several criteria for harvesting based on a work-study survey of harvesting on a number of farms in the Lothian region of south east Scotland (R7A14). They suggest that harvesting is possible on a particular day if rainfall on the previous day (P_{n-1}) is less than 1.4 mm. It is reasonable to assume that this rainfall threshold will rise with PET. Two possible generalisations are possible based on an average daily PET at harvest time in this area of 3 mm (Francis, 1981): a) harvest is possible if PET - P_{n-1} is greater than 1.6 mm or b) if PET/P_{n-1} is greater than 2.1.

TABLE 20. METEOROLOGICAL FACTORS AFFECTING FIELD ACTIVITIES - HARVESTING.

	SUB-OPTIMAL CONDITIONS LOWER LIMIT	SUB-OPTIMAL CONDITIONS UPPER LIMIT	OPTIMAL CONDITIONS	SUPER-OPTIMAL CONDITIONS LOWER LIMIT	SUPER-OPTIMAL CONDITIONS UPPER LIMIT
DATE, PERIOD	RR	RR	RR	RR	RR
PHENOLOGICAL STAGE (ZADOKS)	87	GS 91 MC > 20%	GS 92 - 93 MC 15%	GS 94	NA
TEMPERATURE (°C)	NA	NA	NA	NA	NA
SOIL MOISTURE STATUS	NA	NA	below field capacity	NA	NA
GENERAL WEATHER CONDITIONS	NA	NA	< 1.4 mm on the previous day	NA	NA
DURATION OF THE ACTIVITY (d)	Range			Mean	
Per field	1 - 10			5	
Per region	?			30(w)90(s)	

w = autumn or winter sowing; s = spring sowing

8. Spectral signatures

8.1 Ontogenetic effects

The spectral signature of barley as with other crops changes with growth stage (Table 21). Since barley signatures overlap with those of other crops, phenology is of great importance in its identification. A large component of the difference between wheat and barley spectral signatures measured simultaneously appears to be due to differences in stage of development.

TABLE 21. THE SEASONAL RADIANCE OF SPRING BARLEY CROPS IN NORTH-EAST SCOTLAND IN LANDSAT BANDS 4 (GREEN), 5 (RED), 6 (INFRA-RED) AND 7 (INFRA-RED). DATA FROM WRIGHT & MORRICE, (1988). THE CORRESPONDING DEVELOPMENT STAGES OF BARLEY HAVE BEEN ESTIMATED AS: MAY, TILLERING; JULY, STEM EXTENSION; AUGUST, EAR EMERGENCE. DATA FOR WINTER WHEAT (IN BRACKETS) COLLECTED ON THE SAME DAYS HAVE BEEN INCLUDED FOR COMPARISON.

	LANDSAT BAND			
MONTH	4	5	6	7
May	39-47	25-35	99-124	111-140
	(39-45)	(26-33)	(106-118)	(124-138)
July	40-46	36-45	121-136	128-146
	(38-42)	(33-39)	(108-118)	(121-127)
August	36-44	40-52	62-81	56-84
	(38-39)	(29-36)	(76-83)	(72-84)

8.2 Cultivar differences

Since barley cultivars differ in leaf angle distribution, leaf waxes and phenology, differences in spectral signature should be expected. Differences in the visible spectrum are clear to the naked eye in trials of cultivars.

8.3 Environmental effects

Differences between wheat and barley are likely to be dwarfed by the effects of environment (Table 21). Shortage of both nitrogen and water lead to a premature yellowing of the crop as does the presence of barley yellow dwarf virus. When the plant population density falls below 100 m^{-2}, where tillering and leaf development have been suppressed by drought, where the crops receive low rates of nitrogenous fertiliser or where erect leaved varieties are sown in rows wider apart than 150 mm the soil may be visible throughout the crops life cycle with a consequent effect on spectral signature. The distribution of plants is also important. A field with a uniform distribution of 100 plants m^{-2} will have a different signature from another differing only in that the same number of plants is distributed contagiously with gaps ranging in size from 1-5 m^2, i.e. rather less than one SPOT pixel. Such gaps are typical of the effects of water logging, frost damage, acidity and some pest attacks. Where weeds are uncontrolled, gaps will fill up quickly with annual weeds thus minimising the effect of gaps but grasses such as wild oat (*Avena fatua*) not uncommonly overtop large portions of the crop after ear emergence and remain green longer thus producing a misleading signature. In the Mediterranean region the 'cultura promiscua' of trees, such as olives, among cereals mentioned by the classical Roman authors still persists and must have a drastic effect on spectral signature. It is fortunate that an insignificant part of EC barley is produced under such systems.

Part IV

MODELS OF CROP DEVELOPMENT AND YELD PREDICTION

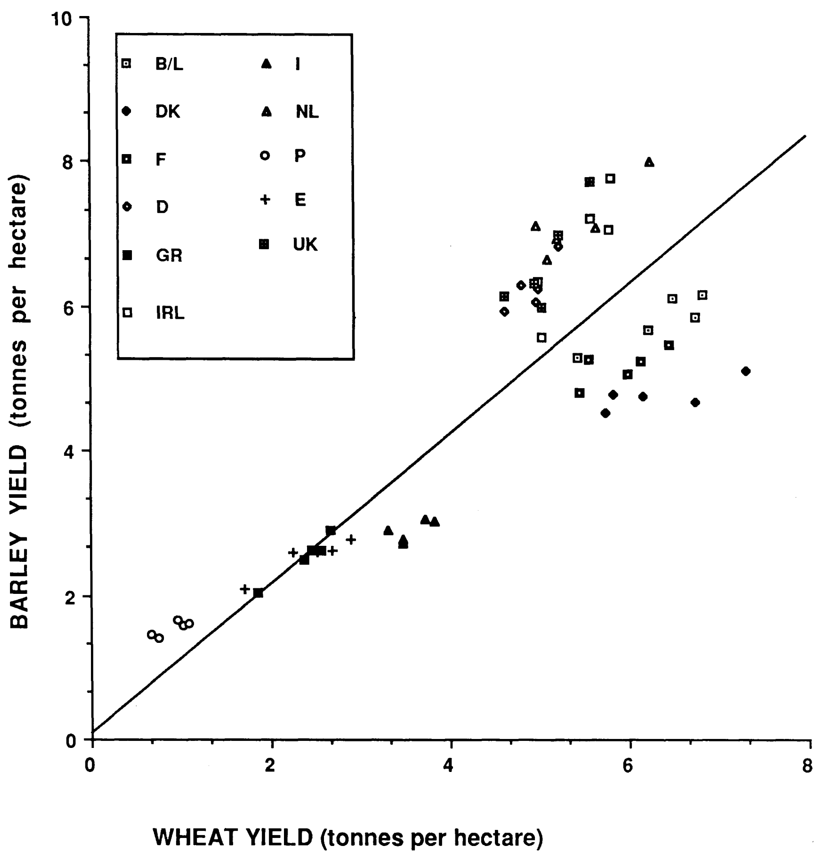
9. Barley models

9.1 Types of model

Several deterministic models of barley yield have been developed but few are in operational use and most have been created to provide predictions of yield at a field rather than a regional scale. Unfortunately, it is unlikely that regional yield can be accurately predicted by running a model developed at a field scale using averaged regional inputs. There are two reasons for this. In the first place most input variables such as, for example, date of sowing and mean temperature in the first decade are unlikely to be normally distributed. Secondly, yield is not a simple linear function of input values. The first difficulty could be overcome by using a more appropriate probability density function and the second by using Monte Carlo simulations. The mathematics of spatial heterogeneity and scaling has been investigated in the analogous case of the relationship between the patchiness of weed and pest distributions and field yield (e.g. Hughes, 1988). This area of mathematical and statistical theory is one that appears to be very important for modelling at a regional scale but which seems to have been neglected by crop modellers. Anderson (1976) has argued that models in general should be stochastic and has pointed out some of the errors that can be introduced into models of crop growth by making them completely deterministic.

An alternative approach to predicting regional barley production might be to work on the basis of deviations from some standard regional yield such as such as the long term average, the maximum or the theoretical potential. If wheat and barley yields are always highly correlated then there would be no need to develop separate models for these two crops. There seems to be a good correlation for Spain, Portugal, Greece and Italy, suggesting that the same factors were affecting both crops (Fig.18) but the correlation is rather poorer for the remaining EC countries. These correlations, representing the last five years only, should be interpreted with caution since the apparent relationships are unlikely to be as strong at the NUTS II level and because there are several factors such as disease and timing of drought which affect the two crops differently and which are of major importance only in a small proportion of years. Consequently, separate models are needed for wheat and barley.

FIG. 18 THE RELATIONSHIP BETWEEN MEAN WHEAT AND BARLEY YIELDS. DATA FROM FAO YEARBOOKS, 1984-1988.



9.2 CERES BARLEY

The Ceres models are a family of mechanistic, deterministic crop growth models developed mainly in the United States of America for many of the world's key agricultural crops. Inputs for all these models consist of a detailed environmental database conforming to guide-lines of the IBSNAT minimum data set (IBSNAT, 1988). The Ceres barley model has been developed from the Ceres wheat model (Ritchie, Godwin & Otter-Nacke, 1990) primarily by altering the parameter values. The barley model has been neither fully validated nor verified and it has not been fully documented.

Model variables are updated daily on the basis of weather data. The growth cycle of the crop is divided into developmental phases each with their own parameter values for growth rate and dry matter partitioning modified by cultivar, weather or other environmental factors. Developmental stage is linked to the emergence of mainstem leaves whose rate of appearance depends on thermal time. Growth rate is calculated as the product of absorbed PAR, which is a function of GAI, using a constant DMRQ (section 6.1). GAI is incremented daily on the basis of available assimilate and SLA. Cultivar is taken account of in terms of genetic coefficients for cold tolerance, photoperiod sensitivity, vernalisation requirement and rate of grain growth (Hunt, 1988). At each stage, deficits of soil water or nitrogen can affect the growth of the modelled crop.

9.3 DAFS MODEL

This mechanistic, deterministic model of barley growth is currently under development by G W Wilson, G Russell and R P Ellis for the Department of Agriculture and Fisheries for Scotland (DAFS) and includes some of the routines from CERES barley. The model is menu driven with a choice of methods being offered for the description of processes. Cultivars are grouped according to fundamental genotypic characters such as vernalisation requirement (winter, spring types), ear type, leaf arrangement and growth habit so that a link can be made between genotype and physiological response to environment. Development stage is a function of thermal time modified by photoperiod and genotype; growth rate is calculated from absorbed PAR; GAI from either SLA or from thermal time and available water; grain number from either biomass at anthesis or from spikelet demography. An important part of the model is the prediction of the dates of the change from vegetative to reproductive growth and of anthesis since yield predictions are extremely sensitive to these variables especially when a range of sowing dates from August to May is possible.

9.4 EPIC

EPIC (Erosion Productivity Impact Calculator) is a model developed by the Agricultural Research Service of the United States Department of Agriculture. This model was developed for use with a number of crop species including barley and has been re-calibrated for conditions in south-west France (Charpenteau *et al.*, 1986). Subsequent development has been for crops other than barley (Cabelguenne *et al.*, 1986). Biomass is incremented daily in response to weather taking account of soil type and management decisions. A major weakness for operation at an EC scale appears to be that calibration is necessary for individual pedo-climatic zones.

9.5 WATCROS AND DAISY

WATCROS was a conceptual model developed by Aslyng and Hansen (1982) for several Danish crops including spring barley. It calculated plant production on a daily basis and derived grain yield using a harvest index of 0.45. Adequate nutrients and an absence of significant weeds, pests and disease were assumed. Photosynthesis was calculated from intercepted solar radiation. In the original model, typical values for green area index were needed as input but Ilola *et al.* (1988) modified it to make GAI a function of thermal time. The effects of a shortage of water were included only in terms of a reduction in photosynthetic rate and no account was taken of the effect on the production of leaf area. Hansen (unpublished) has now improved and extended the model, which has been renamed DAISY, for the Danish Environmental Protection Agency. It now incorporates a more realistic calculation of GAI and a nitrogen sub-model.

9.6 General crop models

A number of general models of crop growth such as BACROS and SUCROS (Penning de Vries & van Laar, 1982; van Keulen & Wolf, 1986) have been developed at Wageningen in the Netherlands. It would be comparatively easy to develop these mechanistic, deterministic models for use with barley, but this has apparently not been done.

9.7 Hough's model

Hough (1975) developed a simple statistical model of the growth of Kenia spring barley based on data from the European Brewery Convention Trials. Unlike the other models considered it therefore used data gathered from throughout Europe. Yield was calculated as the product of plant population density, ears plant^{-1}, grains ear^{-1} and mean grain weight. The PPD was assumed, ears plant^{-1} were calculated from PPD and the potential evaporation in the middle of May and grains ear^{-1} were calculated from PPD and mean temperature at the time of stamen initiation. Grain weights were set as high, medium or low on the basis of the rainfall in the period 20 days before to 10 days after ear emergence and on the presence or absence of mildew. The date of ear emergence was calculated as a function of daylength at crop emergence and the date of harvest ripeness as a function of daylength at crop emergence and potential evaporation. Although there are difficulties in the implementation of this model, notably the sensitivity to plant population density, the difficulty of predicting stamen initiation and the use of a single cultivar, it has a number of attractive features. For example, it could be implemented at a NUTS II scale, it can use ten day weather averages and it uses rules rather than empirical mathematical relationships to calculate grain weight.

9.8 AGROMET/EUROSTAT model

The AGROMET/EUROSTAT model developed at Gembloux forecasts the yields of a range of crops including barley during the growing season. The principle of the model is that yield can be predicted in terms of three components: a trend due to agricultural change, an effect of weather and random variation. The trend is described using multiple regression and time series analysis techniques. Deviations from the trend are correlated with weather variables, such as rainfall, and mean, maximum and minimum temperatures, expressed on a ten-day basis. At the start of the season, predictions are made using long term average weather data and as the season progresses actual observations are substituted for the estimates. The percentage of barley yield variation accounted for in the simulations varied from 58% for a prediction made in February to 76% in June (de Bast, personal communication).

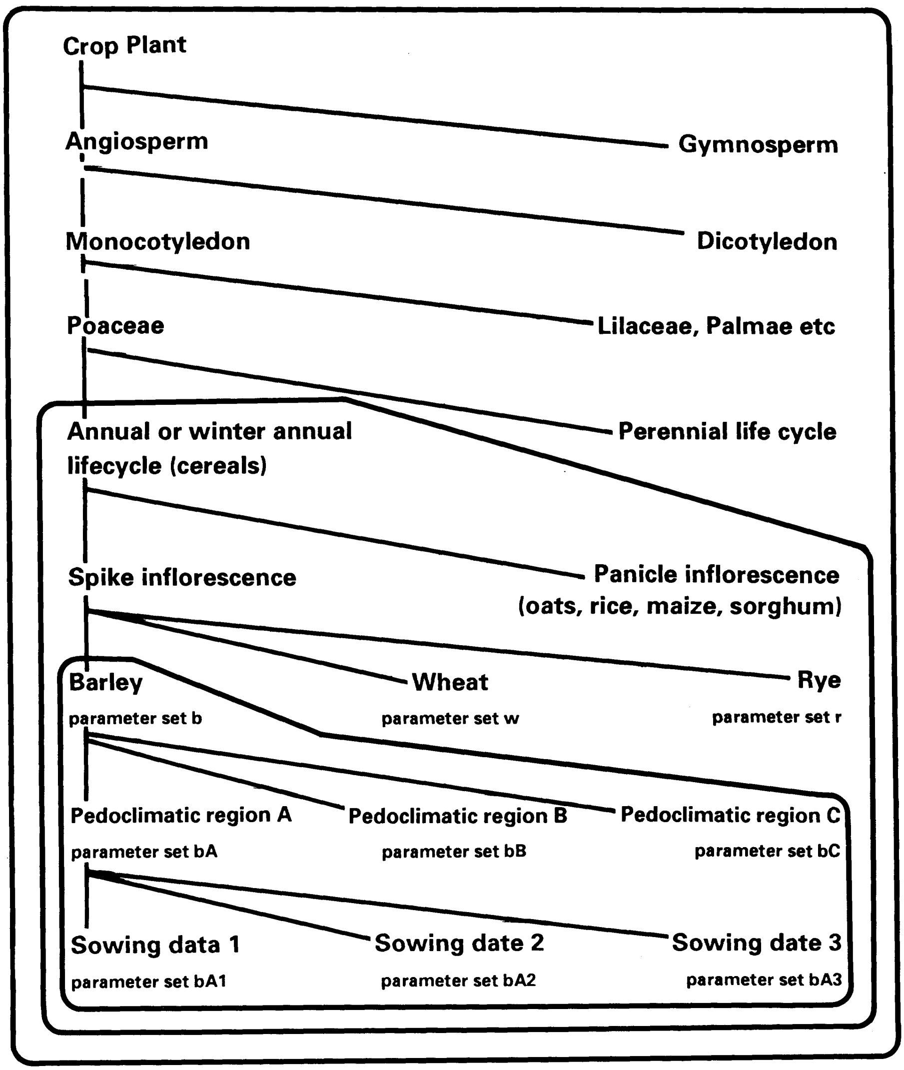
9.9 Other statistical models

Multivariate regression models of barley yield have been used in different parts of the world. Williams *et al.* (1975) accounted for 71% of the variation in barley yields in the Canadian prairie region where water is the major limiting factor. They found that the overall seasonal water deficit, trend in yield over time, the amount of water conserved at the start of the season and the May potential evaporation were all important predictors and that a small but important part of yield variation could be attributed to topography and soil texture. Mukula (1988) presented two regression models for Finland. The simpler one based on monthly values of precipitation and thermal time explained less than 30% of the yield variation while the more complex one which used similar weather variables but averaged over phenological stages rather than months explained up to 70% of the variation. In both the Canadian and Finnish situations only one factor should have dominated the prediction yet a considerable part of the variation remained unaccounted for. Moreover, the form and parameter values of the optimum equations were found to vary with sub-region.

9.10 Choice of model

The choice of an appropriate model of barley yield will depend on the purpose of the model. Models required to give the mean and distribution of barley production in the EC under a range of climatic scenarios, for example, are likely to include more deterministic and mechanistic elements than models to forecast yield in advance of harvest. The mechanistic, deterministic models of barley which have been developed so far are only really applicable at a field rather than a regional scale. Statistical models can produce good regional predictions provided they are calibrated for these regions. However, they can produce erroneous predictions if conditions fall outside the range used in calibration and need to be recalibrated whenever there are changes to farming systems or the characteristics of the barley growing areas. Yield prediction models should include at least some stochastic elements for although barley yield is normally correlated with the biomass at anthesis (i.e. 30-60 days before harvest) major losses can still be caused by severe weather or disease during grainfill or by unfavourable harvesting conditions. Models for annual, biennial and even perennial crops will include representations of similar processes and consideration should be given as to whether a single model of crop growth can be developed. Such a model would have crop species as an input where 'species' has a number of attributes which can used to identify the particular routines required and to derive the apprpriate parameter values. A possible outline scheme for barley which could be elaborated to include other species is outlined in Fig.19. Prototype programs have already been developed which use the language Prolog (Clocksin & Mellish, 1984) to build systems dynamics models of ecological systems by selecting the components of the system and making statements about them (Muetzelfeldt *et al.*, 1987).

FIG. 19. A SCHEME SHOWING HOW PARAMETER VALUES FOR A BARLEY MODEL COULD BE DERIVED IN A GENERALISED CROP MODEL.



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APPENDIX 1 NUTS REGION CODES

REGION CODE	REGION NAME	NUTS LEVEL
R1	**BR DEUTSCHLAND**	**0**
R11	SCHLESWIG-HOLSTEIN	1
R110P	BA FLENSBURG-SCHLESWIG	3
R110Q	BA*KI-NMS-PL-R ECK-SE-STBG	3
R110R	BA*LUEBBECKE-OSTHOLSTEIN	3
R110S	BA DITHMARSCHEN-NORDFRIESL	3
R110T	BA*LAUENBURG-STORMARN	3
R110U	BA*PINNEBERG	3
R12	HAMBURG	1
R13	NIEDERSACHSEN	1
R13A	BRAUNSCHWEIG	2
R13AP	BA*BS-SZ-HELMST-PE-WOLFBUT	3
R13AQ	BA*WOLSBURG-GIFHORN	3
R13AR	BA*GOETTINGEN	3
R13AS	BA*GOSLAR-NTHM-OST	3
R13B	HANNOVER	2
R13BP	BA*HANN-HAMELN-SCHAUMBURG	3
R13BQ	BA*HILDESHEIM-HOLZMINDEN	3
R13BR	BA*DIEPHOLZ-NIENBURG	3
R13C	LUENEBURG	2
R13C1	CELLE	3
R13C2	CUXHAVEN	3
R13C4	LUECHOW-DANNENBERG	3
R13C6	OSTERHOLZ	3
R13C7	ROTENBURG (WUEMME)	3
R13C8	SOLTAU-FALLINGBOSTEL	3
R13C9	STADE	3
R13CA	UELZEN	3
R13CB	VERDEN	3
R13CP	BA HARBURG-LUNEBURG	3
R13D	WESER-EMS	2
R13D8	CLOPPENBURG	3
R13D8	GRAFSCHAFT BENTHEIM	3
R13D9	EMSLAND	3
R13DC	LEER	3
R13DF	VECHTA	3
R13DG	WESERMARSCH	3
R13DH	WITTMUND	3
R13DP	BA*DEHLST-OLDENBG-AMMERLD	3
R13DQ	BA EMDEN-AURICH	3
R13DR	BA OSNABRUCK	3
R13DS	BA WILHELMSHAVEN-FRIESLAND	3
R14	BREMEN	1
R1401	BREMEN, KRFR.ST.	3
R1402	BREMERHAVEN,KRFR.ST	3
R15	NORDRHEIN-WESTFALEN	1
R151	DUESSELDORF	2
R1511	DUESSELDORF,KRFR.ST	3

REGION CODE	REGION NAME	NUTS LEVEL
R1512	DUISBURG, KRFR.ST	3
R1513	ESSEN, KRFR.ST.	3
R1516	MUELHEIM A.D. RUHR, KRFR.ST	3
R1517	OBERHAUSEN, KRFR.ST	3
R1518	REMSCHEID, KRFR.ST	3
R1519	SOLINGEN, KRFR.ST	3
R151A	WUPPERTAL, KRFR.ST	3
R151C	METTMANN	3
R151P	BA KREFELD-VIERZEN	3
R151Q	BA MOENCHENGLADBH-NEUSS	3
R151R	BA KLEVE-WESEL	3
R152	KOELN	2
R1521	AACHEN, KRFR.ST	3
R1523	KOELN, KRFR.ST	3
R1525	AACHEN	3
R1526	DUEREN	3
R1527	ERFTKREIS	3
R1528	EUSKIRCHEN	3
R1529	HEINSBERG	3
R152A	OBERBERGISCHER KREIS	3
R152P	BA BONN-RHEIN SIEG	3
R152Q	BA LEVERKN-RHEIN BERGISCH	3
R153	MUENSTER	2
R1531	BOTTROP, KRFR.ST	3
R1532	GELSENKIRCHEN,KRFR.ST	3
R1533	MUENSTER (WESTF), KRFR.ST	3
R1536	RECKLINGHAUSEN	3
R1537	STEINFURT	3
R1538	WARENDORF	3
R153P	BA BORKEN-COESFELD	3
R154	DETMOLD	2
R1545	LIPPE	3
R154P	BA BIELEFD-GUTERSLOH	3
R154Q	BA HERF-MINDEN-LU'CKE	3
R154R	BA HOEXTER-PADERBURG	3
R155	ARNSBERG	2
R1551	BOCHUM, KRFR.ST	3
R1552	DORTMUND, KRFR.ST	3
R1554	HAMM, KRFR.ST	3
R1555	HERNE, KRFR.ST	3
R1557	HOCHSAUERLANDKREIS	3
R1558	MAERKISCHER KREIS	3
R1559	OLPE	3
R155A	SIEGEN	3
R155B	SOEST	3
R155C	UNNA	3
R155P	BA HAGEN-ENNEPE RJP	3
R16	HESSEN	1

REGION CODE	REGION NAME	NUTS LEVEL
R1	**BR DEUTSCHLAND**	**0**
R16A	DARMSTADT	2
R16A9	MAIN-KINZIG-KREIS	3
R16AE	WETTERAUKREIS	3
R16AP	BA DARMSTADT-DIEBG	3
R16AQ	BA*FRANKFURT AM MAIN KRFR.ST	3
R16AR	BA*OF-GRGERAU-HOCHTNS-MAIN TNS	3
R16AS	BA WIESBDN-RHEINGAU TNS	3
R16AT	BA BERGSTR-ODENWALL	3
R16B	GIESSEN	2
R16B3	LIMBURG-WEILBURG	3
R16B5	VOGELSBERGKREIS	3
R16BP	BA*GIESS-LAHNDL-MBRG BDKF	3
R16C	KASSEL	2
R16C2	FULDA	3
R16C3	HERSFELD-ROTENBURG	3
R16C5	SCHWALM-EDER-KREIS	3
R16C6	WALDECK-FRANKEN.	3
R16C7	WERRA-MEISSNER-.	3
R16CP	BA KASSEL	3
R17	RHEINLAND PFALZ	1
R171	KOBLENZ	2
R1713	ALTENKIRCHEN (WESTERWALD)	3
R171A	RHEIN-LAHN-KREIS	3
R171B	NEUWIED	3
R171B	WESTER WALDKREIS	3
R171P	BA*KO-AHW-COCH-MAYEN-RH HR	3
R171Q	BA KREUNACH-BIRKENFELD	3
R172	TRIER	2
R1722	BERNKASTEL-WITTLICH	3
R1723	BITBURG-PRUEM	3
R172P	BA TRIER-TR SAARBURG	3
R172Q	BA*DAUN	3
R173	RHEINHESSEN-PFALZ	2
R173D	DONNERSBERGKREIS	3
R173E	GERMERSHEIM	3
R173G	KUSEL	3
R173P	BA KAISERSLAUTERN	3
R173Q	BA LD-SUW-NWEINSTR-BDDK	3
R173R	BA LUNIN-FRANKTK-SPEYER	3
R173S	BA MAINZ-MZ-BINGEN	3
R173T	BA PIRMASENS-SBRUCKEN	3
R173U	BA ALZEY WO-WORMS	3
R18	BADEN-WUERTTEMBERG	1
R181	STUTTGART	2
R1811	STUTTGART.STADTKR	3
R1812	BOEBLINGEN	3
R1813	ESSLINGEN	3
R1814	GOEPPINGEN	3
R1815	LUDWIGSBURG	3
R1816	REMS-MURR-KREIS	3
R1819	HOHENLOHEKREIS	3
R181A	SCHWAEBISCH HALL	3
R181B	MAIN-TAUBER KREIS	3

REGION CODE	REGION NAME	NUTS LEVEL
R181C	HEIDENHEIM	3
R181D	OSTALBKREIS	3
R181P	BA HEILBRONN	3
R182	KARLSRUHE	2
R1827	NECKAR-ODENWALD-KREIS	3
R182A	CALW	3
R182C	FREUDENSTADT	3
R182P	BA RASTATT-BADEN BADEN	3
R182Q	BA KARLSRUHE	3
R182R	BA HOLBG-RH NECKAR MANNH	3
R182S	BA PFORZHEIM-ENZKREIS	3
R183	FREIBURG	2
R1833	EMMENDINGEN	3
R1834	ORTENAUKREIS	3
R1836	SCHWARZWALD-BAAR-KREIS	3
R1838	KONSTANZ	3
R1839	LOERRACH	3
R183A	WALDSHUT	3
R183P	BA FRBG-BREISGAU-HOCHSCHWLD	3
R183Q	BA ROTTWEIL-TUTTLINGEN	3
R184	TUEBINGEN	2
R1843	ZOLLERNALBKREIS	3
R1846	BIBERACH	3
R1847	BODENSEEKREIS	3
R1848	RAVENSBURG	3
R1849	SIGMARINGEN	3
R184P	BA REUTLINGEN-TUEBINGEN	3
R184Q	BA ULM ALB DONAU	3
R19	BAYERN	1
R191	OBERBAYERN	2
R1914	ALTOETTING	3
R1915	BAD TOELZ-WOLFRATSHAUSEN	3
R1917	DACHAU	3
R1918	EBERSBERG	3
R191A	ERDING	3
R191B	FREISING	3
R191C	FUERSTENFELDBRUCK	3
R191D	GARMISCH-PARTENKIRCHEN	3
R191E	LANDSBERG A. LECH	3
R191F	MIESBACH	3
R191G	MUEHLDORF A. INN	3
R191I	NEUBURG-SCHROBENHAUSEN	3
R191L	STARNBERG	3
R191N	WEILHEIM-SCHONGAU	3
R191P	BA IN-EICHSTATT-PFAFFHOFEN	3
R191Q	BA MUENCHEN	3
R191R	BA ROSENHEIM	3
R191S	BA BERCHTGALD-TRAUNSTEIN	3
R192	NIEDERBAYERN	2
R1924	DEGGENDORF	3
R1925	DINGOLFING-LANDAU	3
R1926	FREYUNG-GRAFENAU	3
R192A	REGEN	3
R192B	ROTTAL-INN	3
R192P	BA LANDSHUT-KEILHEIM	3
R192Q	BA PASSAU	3

REGION CODE	REGION NAME	NUTS LEVEL
R1	**BR DEUTSCHLAND**	**0**
R192R	BA STRAUBING	3
R193	OBERPFALZ	2
R1935	CHAM	3
R1936	NEUMARKT I.D. OPF	3
R1939	SCHWANDORF	3
R193P	BA AMBERG-AMBG SALZBACH	3
R193Q	BA REGENSBURG	3
R193R	BA*WEID-NST-TIRSCHTH	3
R194	OBERFRANKEN	2
R1948	FORCHHEIM	3
R194A	KRONACH	3
R194B	KULMBACH	3
R194C	LICHTENFELS	3
R194P	BA BAMBERG	3
R194Q	BA BAYREUTH	3
R194R	BA COBURG	3
R194S	BA*HOF-WUNDSIEDEL	3
R195	MITTELFRANKEN	2
R1959	NEUSTADT A.D.AISCH-BAD WINDSHE	3
R195C	WEISSENBURG-GUNZENHAUSEN	3
R195P	BA ANSBACH	3
R195Q	BA ER-NEURN-SCHWABH	3
R195R	BA FUERTH	3
R196	UNTERFRANKEN	2
R1965	BAD KISSINGEN	3
R1966	HASSBERGE	3
R1967	KITZINGEN	3
R1968	MAIN-SPESSART	3
R1969	MILTENBERG	3
R196A	RHOEN-GRABFELD	3
R196P	BA ASCHAFFENBURG	3
R196Q	BA SCHWEINFURT	3
R196R	BA WUERZBURG	3
R197	SCHWABEN	2
R1977	DILLINGEN A.D. DONAU	3
R1978	DONAU-RIES	3
R1979	GUENZBURG	3
R197A	LINDAU-BODENSEE	3
R197B	NEU-ULM	3
R197P	BA A-AICHACH FRIEDBERG	3
R197Q	BA KAUFBEUREN-OSTALLGAEU	3
R197	BA KEMPTEN-OBERALLGAEU	3
R197S	BA MEMMINGEN-UNTERALLGAEU	3
R1A	**SAARLAND**	1
R1A01	SAARBRUECKEN,STADTVERB.	2
R1A02	MERZIG-WADERN	3
R1A03	NEUNKIRCHEN	3
R1A04	SAARLOUIS	3
R1A05	SAAR-PFALZ-KREIS	3
R1A06	SANKT WENDEL	3
R1B	**BERLIN(WEST)**	1

REGION CODE	REGION NAME	NUTS LEVEL
R2	**FRANCE**	**0**
R21	**ILE DE FRANCE**	1
R2101	PARIS	3
R2102	SEINE-ET -MARNE	3
R2103	YVELINES	3
R2104	ESSONNE	3
2R105	HAUTS-DE-SEINE	3
R2106	SEINE-SAINT-DENIS	3
R2107	VAL-DE-MARNE	3
R2108	VAL-D'OISE	3
R22	**BASSIN PARISIEN**	1
R221	CHAMPAGNE-ARDENNE	2
R2211	ARDENNES	3
R2212	AUBE	3
R2213	MARNE	3
R2214	HAUTE-MARNE	3
R222	PICARDIE	2
R2221	AISNE	3
R2222	OISE	3
R2223	SOMME	3
R223	HAUTE-NORMANDIE	2
R2231	EURE	3
R2232	SEINE-MARITIME	3
R224	CENTRE	2
R2241	CHER	3
R2242	EURE-ET-LOIR	3
R2243	INDRE	3
R2244	INDRE-ET-LOIRE	3
R2245	LOIR-ET-CHER	3
R2246	LOIRET	3
R225	BASSE-NORMANDIE	2
R2251	CALVADOS	3
R2252	MANCHE	3
R2253	ORNE	3
R226	BOURGOGNE	2
R2261	COTE-D'OR	3
R2262	NIEVRE	3
R2263	SAONE-ET-LOIRE	3
R2264	YONNE	3
R23	**NORD - PAS-DE-CALAIS**	1
R2301	NORD	3
R2302	PAS-DE-CALAIS	3
R24	**EST**	1
R241	LORRAINE	2
R2411	MEURTHE-ET-MOSELLE	3
R2412	MEUSE	3
R2413	MOSELLE	3
R2414	VOSGES	3
R242	ALSACE	2
R2421	BAS-RHIN	3
R2422	HAUT-RHIN	3
R243	FRANCHE-COMTE	2
R2431	DOUBS	3

REGION CODE	REGION NAME	NUTS LEVEL
R2	**FRANCE**	**0**
R2432	JURA	3
R2433	HAUTE-SAONE	3
R2434	TERRITOIRE DE BELFORT	3
R25	**OUEST**	1
R251	PAYS DE LA LOIRE	2
R2511	LOIRE-ATLANTIQUE	3
R2512	MAINE-ET-LOIRE	3
R2513	MAYENNE	3
R2514	SARTHE	3
R2515	VENDEE	3
R252	BRETAGNE	2
R2521	COTES-DU-NORD	3
R2522	FINISTERE	3
R2523	ILLE-ET-VILAINE	3
R2524	MORBIHAN	3
R253	POITOU-CHARENTES	2
R2531	CHARENTE	3
R2532	CHARENTE-MARITIME	3
R2533	DEUX-SEVRES	3
R2534	VIENNE	3
R26	**SUD-OUEST**	1
R261	AQUITAINE	2
R2611	DORDOGNE	3
R2612	GIRONDE	3
R2613	LANDES	3
R2614	LOT-ET-GARONNE	3
R2615	PYRENEES-ATLANTIQUES	3
R262	MIDI-PYRENEES	2
R2621	ARIEGE	3
R2622	AVEYRON	3
R2623	HAUTE-GARONNE	3
R2624	GERS	3
R2625	LOT	3
R2626	HAUTES-PYRENNES	3
R2627	TARN	3
R2628	TARN-ET-GARONNE	3
R263	LIMOUSIN	2
R2631	CORREZE	3
R2632	CREUSE	3
R2633	HAUTE-VIENNE	3
R27	**CENTRE-EST**	1
R271	RHONE-ALPES	2
R2711	AIN	3
R2712	ARDECHE	3
R2713	DROME	3
R2714	ISERE	3
R2715	LOIRE	3
R2716	RHONE	3
R2717	SAVOIE	3
R2718	HAUTE-SAVOIE	3
R272	AUVERGNE	2
R2721	ALLIER	3
R2722	CANTAL	3
R2723	HAUTE-LOIRE	3
R2724	PUY-DE-DOME	3
R28	**MEDITERRANEE**	1
R281	LANGUEDOC-ROUSSILLON	2
R2811	AUDE	3
R2812	GARD	3
R2813	HERAULT	3
R2814	LOZERE	3
R2815	PYRENEES-ORIENTALES	3
R282	PROVENCE-ALPES-COTE D'AZUR	2
R2821	ALPES-DE-HAUTE-PROVENCE	3
R2822	HAUTES-ALPES	3
R2823	ALPES-MARITIMES	3
R2824	BOUCHES-DU-RHONE	3
R2825	VAR	3
R2826	VAUCLUSE	3
R283	CORSE	2
R2831	CORSE DU SUD	3
R2832	HAUTE-CORSE	3
R3	**ITALIA**	**0**
R31	**NORD OVEST**	1
R311	PIEMONTE	2
R3111	TORINO	3
R3112	VERCELLI	3
R3113	NOVARA	3
R3114	CUNEO	3
R3115	ASTI	3
R3116	ALESSANDRIA	3
R312	VALLE D'AOSTA	2
R313	LIGURIA	2
R3131	IMPERIA	3
R3132	SAVONA	3
R3133	GENOVA	3
R3134	LA SPEZIA	3
R32	**LOMBARDIA**	1
R3201	VARESE	3
R3202	COMO	3
R3203	SONDRIO	3
R3204	MILANO	3
R3205	BERGAMO	3
R3206	BRESCIA	3
R3207	PAVIA	3
R3208	CREMONA	3
R3209	MANTOVA	3
R33	**NORD EST**	1
R331	TRENTINO-ALTO ADIGE	2
R3311	BOLZANO-BOZEN	3
R3312	TRENTO	3
R332	VENETO	2
R3321	VERONA	3
R3322	VICENZA	3

REGION CODE	REGION NAME	NUTS LEVEL
R3	**ITALIA**	**0**
R3323	BELLUNO	3
R3324	TREVISO	3
R3325	VENEZIA	3
R3326	PADOVA	3
R3327	ROVIGO	3
R333	FRIULI-VENEZIA GIULIA	2
R331	PORDENONE	3
R3332	UDINE	3
R3333	GORIZIA	3
R3334	TRIESTE	3
R34	**EMILIA-ROMAGNA**	1
R3401	PIACENZA	3
R3402	PARMA	3
R3403	REGGIO NELL'EMILIA	3
R3404	MODENA	3
R3405	BOLOGNA	3
R3406	FERRARA	3
R3407	RAVENNA	3
R3408	FORLI	3
R35	**CENTRO**	1
R351	TOSCANA	2
R3511	MASSA-CARRARA	3
R3512	LUCCA	3
R3513	PISTOIA	3
R3514	FIRENZE	3
R3515	LIVORNO	3
R3516	PISA	3
R3517	AREZZO	3
R3518	SIENA	3
R3519	GROSSETO	3
R352	UMBRIA	2
R3521	PERUGIA	3
R3522	TERNI	3
R353	MARCHE	2
R3531	PESARO E URBINO	3
R3532	ANCONA	3
R3533	MACERATA	3
R3534	ASCOLI PICENO	3
R36	**LAZIO**	1
R3601	VITERBO	3
R3602	RIETI	3
R3603	ROMA	3
R3604	LATINA	3
R3605	FROSINONE	3
R37	**CAMPANIA**	1
R3701	CASERTA	3
R3702	BENEVENTO	3
R3703	NAPOLI	3
R3704	AVELLINO	3
R3705	SALERNO	3
R38	**ABRUZZI-MOLISE**	1
R381	ABRUZZI	2

REGION CODE	REGION NAME	NUTS LEVEL
R3811	L'AQUILA	3
R3812	TERAMO	3
R3813	PESCARA	3
R3814	CHIETI	3
R382	MOLISE	2
R3821	ISERNIA	3
R3822	CAMPOBASSO	3
R39	**SUD**	1
R391	PUGLIA	2
R3911	FOGGIA	3
R3912	BARI	3
R3913	TARANTO	3
R3914	BRINDISI	3
R3915	LECCE	3
R392	BASILICATA	2
R3921	POTENZA	3
R3922	MATERA	3
R393	CALABRIA	2
R3931	COSENZA	3
R3932	CATANZARO	3
R3933	REGGIO DI CALABRIA	3
R3A	**SICILIA**	1
R3A01	TRAPANI	3
R3A02	PALERMO	3
R3A03	MESSINA	3
R3A04	AGRIGENTO	3
R3A05	CALTANISSETTA	3
R3A06	ENNA	3
R3A07	CATANIA	3
R3A08	RAGUSA	3
R3A09	SIRACUSA	3
R3B	**SARDEGNA**	1
R3B01	SASSARI	3
R3B02	NUORO	3
R3B03	ORISTANO	3
R3B04	CAGLIARI	3
R4	**NEDERLAND**	**0**
R41	**NOORD-NEDERLAND**	1
R411	GRONINGEN	2
R4111	OOST-GRONINGEN	3
R4112	DELFZIJL E.O	3
R4113	OVERIG GRONINGEN	3
R412	FRIESLAND	2
R4121	NOORD-FRIESLAND	3
R4122	ZUIDWEST-FRIESLAND	3
R4123	ZUIDOOST-FRIESLAND	3
R413	DRENTHE	2
R4131	NOORD-DRENTHE	3
R4132	ZUIDOOST-DRENTHE	3
R4133	ZUIDWEST-DRENTHE	3
R42	**OOST-NEDERLAND**	1
R421	OVERIJSSEL	2

REGION CODE	REGION NAME	NUTS LEVEL
R4	**NEDERLAND**	**0**
R4211	NOORD-OVERIJSSEL	3
R4212	ZUIDWEST-OVERIJSSEL	3
R4213	TWENTE	3
R422	GELDERLAND	2
R4221	VELUWE	3
R4222	ACHTERHOEK	3
R4223	ARNHEM-NIJMEGEN	3
R4224	ZUIDWEST-GELDERLAND	3
R4225	Z IJ.-POLDERS	3
R45	**ZUID-NEDERLAND**	1
R451	NOORD-BRABANT	2
R4511	WEST-NOORD-BRABANT	3
R4512	MIDDEN-NOORD-BRABANT	3
R4513	NOORDOOST-NOORD-BRABANT	3
R4514	ZUIDOOST-NOORD-BRABANT	3
R452	LIMBURG	2
R4521	NOORD-LIMBURG	3
R4522	MIDDEN-LIMBURG	3
R4523	ZUID-LIMBURG	3
R47	**WEST-NEDERLAND**	1
R471	UTRECHT	2
R472	NOORD-HOLLAND	2
R4721	KOP VAN NOORD-HOLLAND	3
R4722	ALKMAAR E.O	3
R4723	IJMOND	3
R4724	AGGLOM. HAARLEM	3
R4725	ZAANSTREEK	3
R4726	GROOT-AMSTERDAM	3
R4727	GOOI EN VECHTSTREEK	3
R473	ZUID HOLLAND	2
R4731	AGGLOM. LEIDEN	3
R4732	AGGLOM.'S GRAVENHAGE	3
R4733	DELFT EN WESTLAND	3
R4734	OOSTELIJK-ZUID-HOLLAND	3
R4735	GROOT-RIJNMOND	3
R4736	ZUIDOOST-ZUID-HOLLAND	3
R474	ZEELAND	2
R4741	ZEEUWSCH-VLAANDEREN	3
R4742	OVERIG ZEELAND	3
R5	**BELGIQUE - BELGIE**	**0**
R51	**VLAAMS GEWEST**	1
R52	**REGION WALLONNE**	1
R53	**BRUXELLES-BRUSSEL**	1
R501	ANTWERPEN	2
R5011	ANTWERPEN (ARR)	3
R5012	MECHELEN	3
R5013	TURNHOUT	3
R502	BRABANT	2
R5021	BRUXELLES-CAP-BRUSSEL	3
R5022	HALLE-VILYDORDE	3
R5023	LEUVEN	3
R5024	NIVELLES	3
R503	HAINAUT	2
R5031	ATH	3
R5032	CHARLEROI	3
R5033	MONS	3
R5034	MOUSCRON	3
R5035	SOIGNIES	3
R5036	THUIN	3
R5037	TOURNAI	3
R504	LIEGE	2
R5041	HUY	3
R5042	LIEGE (ARR)	3
R5043	VERVIERS	3
R5044	HAREME	3
R505	LIMBURG	2
R5051	HASSELT	3
R5052	HAASEIK	3
R5053	TONGEREN	3
R506	LUXEMBOURG	2
R5061	ARLON	3
R5062	BASTOGNE	3
R5063	MARCHE-EN-FAMENNE	3
R5064	NEUFCHATEAU	3
R5065	VIRTON	3
R507	NAMUR	2
R5071	DINAN	3
R5072	NAMUR (ARR)	3
R5073	PHILIPPEVILLE	3
R508	OOST-VLAANDEREN	2
R5081	AALST	3
R5082	DENDERMONDE	3
R5083	EEKLO	3
R5084	GENT	3
R5085	OUDENAARDE	3
R5086	SINT-NIKLAAS	3
R509	WEST-VLAANDEREN	2
R5091	BRUGGE	3
R5092	DIKSMUIDE	3
R5093	IEPER	3
R5094	KORTRIJK	3
R5095	OOSTENDE	3
R5096	ROESELARE	3
R5097	TIELT	3
R5098	VEURNE	3
R6	**LUXEMBOURG**	**0**
R7	**UNITED KINGDOM**	**0**
R71	**NORTH**	1
R711	CLEVELAND, DURHAM	2
R7111	CLEVELAND	3
R7112	DURHAM	3

REGION CODE	REGION NAME	NUTS LEVEL
R5	**UNITED KINGDOM**	**0**
R712	CUMBRIA	2
R713	NORTHUMBERLAND, TYNE AND WEAR	2
R7131	NORTHUMBERLAND	3
R7132	TYNE AND WEAR	3
R72	**YORKSHIRE AND HUMBERSIDE**	1
R721	HUMBERSIDE	2
R722	NORTH YORKSHIRE	2
R723	SOUTH YORKSHIRE	2
R724	WEST YORKSHIRE	2
R73	**EAST MIDLANDS**	1
R731	DERBYSHIRE, NOTTINGHAMSHIRE	2
R7311	DERBYSHIRE	3
R7312	NOTTINGHAMSHIRE	3
R732	LEICESTERSHIRE, NORTHAMP'SHIRE	2
R7321	LEICESTERSHIRE	3
R7322	NORTHAMPTONSHIRE	3
R733	LINCOLNSHIRE	2
R74	**EAST ANGLIA**	1
R7401	CAMBRIDGESHIRE	3
R7402	NORFOLK	3
R7403	SUFFOLK	3
R75	**SOUTH EAST**	1
R751	BEDFORD, HERTFORDSHIRE	2
R7511	BEDFORDSHIRE	3
R7512	HERTFORDSHIRE	3
R752	BERK, BUCKINGHAM, OXFORDSHIRE	2
R7521	BERKSHIRE	3
R7522	BUCKINGHAMSHIRE	3
R7523	OXFORDSHIRE	3
R753	EAST SUSSEX, SURREY, WEST SUSSEX	2
R7531	EAST SUSSEX	3
R7532	SURREY	3
R7533	WEST SUSSEX	3
R754	ESSEX	2
R755	GREATER LONDON	2
R756	HAMPSHIRE, ISLE OF WIGHT	2
R7561	HAMPSHIRE	3
R7562	ISLE OF WIGHT	3
R757	KENT	2
R76	**SOUTH WEST**	1
R761	AVON, GLOUCESTERSHIRE, WILTSHIRE	2
R7611	AVON	3
R7612	GLOUCESTERSHIRE	3
R7613	WILTSHIRE	3
R762	CORNWALL, DEVON	2
R7621	CORNWALL	3
R7622	DEVON	3
R763	DORSET, SOMERSET	2
R7631	DORSET	3
R7632	SOMERSET	3
R77	**WEST MIDLANDS**	1
R771	HEREFORD,WORCESTER,WARWICKS.	2

REGION CODE	REGION NAME	NUTS LEVEL
R7711	HEREFORD AND WORCESTER	3
R7712	WARWICKSHIRE	3
R772	SALOP, STAFFORDSHIRE	2
R7721	SALOP	3
R7722	STAFFORDSHIRE	3
R773	WEST MIDLANDS (COUNTY)	2
R78	**NORTH WEST**	1
R781	CHESHIRE	2
R782	GREATER MANCHESTER	2
R783	LANCASHIRE	2
R784	MERSEYSIDE	2
R79	**WALES**	1
R791	CLWYD, DYFED, GWYNEDD, POWYS	2
R7911	CLWYD	3
R7912	DYFED	3
R7913	GWYNEDD	3
R7914	POWYS	3
R792	GWENT, GLAMORGAN	2
R7921	GWENT	3
R7922	MID GLAMORGAN	3
R7923	SOUTH GLAMORGAN	3
R7924	WEST GLAMORGAN	3
R7A	**SCOTLAND**	1
R7A13	FIFE	3
R7A1	BORDERS-CENTRAL-FIFE-LOTHIAN-TAYSIDE	2
R7A11	BORDERS	3
R7A12	CENTRAL	3
R7A13	FIFE	3
R7A14	LOTHIAN	3
R7A15	TAYSIDE	3
R7A2	DUMFRIES & GALLOWAY, STRATHCLYDE	2
R7A21	DUMFRIES AND GALLOWAY	3
R7A22	STRATHCLYDE	3
R7A3	HIGHLANDS, ISLANDS	2
R7A31	HIGHLANDS	3
R7A32	ISLANDS	3
R7A4	GRAMPIAN	2
R7B	**NORTHERN IRELAND**	1
R8	**IRELAND**	**0**
R8001	EAST	3
R8002	SOUTH WEST	3
R8003	SOUTH EAST	3
R8004	NORTH EAST	3
R8005	MID WEST	3
R8006	DONEGAL	3
R8007	MIDLANDS	3
R8009	NORTH WEST	3

REGION CODE	REGION NAME	NUTS LEVEL
R9	DENMARK	0
R901	HOVEDSTADSREGIONEN	2
R9011	KOBENHAVN OG FREDERIKSBERG KOM.	3
R9012	KOBENHAVNS AMTSKOMMUNE	3
R9013	FREDERIKSBORG AMTSKOMMUNE	3
R9014	ROSKILDE AMTSKOMMUNE	3
R902	OST FOR STOREBAELT, EX.HOVEDST	2
R9021	VESTSJAELLANDS AMTSKOMMUNE	3
R9022	STORSTROMS AMTSKOMMUNE	3
R9023	BORNHOLMS AMTSKOMMUNE	3
R903	VEST FOR STOREBAELT	2
R9031	FYNS AMTSKOMMUNE	3
R9032	SONDERJYLLANDS AMTSKOMMUNE	3
R9033	RIBE AMTSKOMMUNE	3
R9034	VEJLE AMTSKOMMUNE	3
R9035	RINGKOBING AMTSKOMMUNE	3
R9036	AARHUS AMTSKOMMUNE	3
R9037	VIBORG AMTSKOMMUNE	3
R9038	NORDJYLLANDS AMTSKOMMUNE	3
RA1	VOREIA ELLADA	1
RA12	KENTRIKI KAI DYTIKI MAKEDONIA	2
RA121	THESSALONIKI	3
RA122	CHALKIDIKI	3
RA123	KILKIS	3
RA124	PIERIA	3
RA125	IMATHIA	3
RA126	PELLA	3
RA127	FLORINA	3
RA128	KASTORIA	3
RA129	KOZANI	3
RA12A	GREVENA	3
RA14	THESSALIA	2
RA141	LARISA	3
RA142	MAGNISIA	3
RA143	TRIKALA	3
RA144	KARDITSA	3
RA15	ANATOLIKA MAKEDONIA	2
RA151	KAVALA	3
RA152	SERRES	3
RA153	DRAMA	3
RA18	THRAKI	2
RA181	RODOPI	3
RA182	XANTHI	3
RA183	EVROS	3
RA	GREECE	0
RA2	KENTRIKI ELLADA	1
RA21	ANATOLIKA STEREA KAI NISIA	2
RA211	ATTIKA	3
RA212	VOIOTII	3
RA213	FTHIOTIDA	3
RA214	FOKIDA	3
RA215	EVRYTANIA	3
RA216	EYVOIA	3
RA217	KYKLADES	3
RA23	PELOPONNISOS KAI DYTIKI STEREA	2
RA231	KORINTHIA	3
RA232	ARGOLIDA	3
RA233	ACHAIA	3
RA234	ILEIA	3
RA235	MESSINIA	3
RA236	LAKONIA	3
RA237	ARKADIA	3
RA238	AITOLOAKARNANIA	3
RA239	ZAKYNTHOS	3
RA23A	KEFALLINIA	3
RA27	IPEIROS	2
RA271	IOANNINA	3
RA272	ARTA	3
RA273	PREVEZA	3
RA274	THESPROTIA	3
RA275	KERKYRA	3
RA276	LEFKADA	3
RA3	ANATOLIKA KAI NOTIA NISIA	1
RA36	KRITI	2
RA361	IRAKLEIO	3
RA362	CHANIA	3
RA363	LASITHI	3
RA364	RETHYMNI	3
RA39	NISIA ANATOLIKOU AIGAIOU	2
RA391	LESVOS	3
RA392	DODEKANISOS	3
RA393	SAMOS	3
RA394	CHIOS	3
RB	ESPANA	0
RB1	NOROESTE	1
RB11	GALICIA	2
RB111	LA CORUNA	3
RB112	LUGO	3
RB113	ORENSE	3
RB114	PONTEVEDRA	3
RB12	ASTURIAS	2
RB13	CANTABRIA	2
RB2	NORESTE	1
RB21	PAIS VASCO	2
RB211	ALAVA	3
RB212	GUIPUZCOA	3
RB213	VIZCAYA	3
RB22	NAVARRA	2
RB23	RIOJA	2
RB24	ARAGON	2
RB241	HUESCA	3
RB242	TERUEL	3

REGION CODE	REGION NAME	NUTS LEVEL
RB243	ZARAGOZA	3
RB3	**MADRID**	1
RB4	**CENTRO**	1
RB41	CASTILLA - LEON	2
RB411	AVILA	3
RB412	BURGOS	3
RB413	LEON	3
RB414	PALENCIA	3
RB415	SALAMANCA	3
RB416	SEGOVIA	3
RB417	SORIA	3
RB418	VALLADOLID	3
RB419	ZAMORA	3
RB42	CASTILLA - LA MANCHA	2
RB421	ALBACETE	3
RB422	CIUDAD REAL	3
RB423	CUENCA	3
RB424	GUADALAJARA	3
RB425	TOLEDO	3
RB43	EXTREMADURA	2
RB431	BADAJOZ	3
RB432	CACERES	3
RB5	**ESTE**	1
RB51	CATALUNA	2
RB511	BARCELONA	3
RB512	GERONA	3
RB513	LERIDA	3
RB514	TARRAGONA	3
RB52	COMUNIDAD VALENCIANA	2
RB521	ALICANTE	3
RB522	CASTELLON DE LA PLANA	3
RB523	VALENCIA	3
RB53	BALEARES	2
RB6	**SUR**	1
RB61	ANDALUCIA	2
RB611	ALMERIA	3
RB612	CADIZ	3
RB613	CORDOBA	3
RB614	GRANADA	3
RB615	HUELVA	3
RB616	JAEN	3
RB617	MALAGA	3
RB618	SEVILLA	3
RB62	MURCIA	2
RB63	CEUTA Y MELILLA	2
RB631	CEUTA	3
RB632	MELILLA	3
RB7	**CANARIAS**	1
RB711	LAS PALMAS	3
RB712	STA. CRUZ DE TENERIFE	3

REGION CODE	REGION NAME	NUTS LEVEL
RC	**PORTUGAL**	**0**
RC1	**NORTE DO CONTINENTE**	1
RC11	NORTE	2
RC111	MINHO-LIMA	3
RC112	CAVADO	3
RC113	AVE	3
RC114	GRANDE-PORTO	3
RC115	TAMEGA	3
RC116	ENTRE DOURO E VOUGA	3
RC117	DOURO	3
RC118	ALTO TRAS-OS-MONTES	3
RC12	**CENTRO**	2
RC121	BAIXO VOUGA	3
RC122	BAIXO MONDEGO	3
RC123	PINHAL LITORAL	3
RC124	PINHAL INTERIOR	3
RC125	DAO - LAFOES	3
RC126	SERRA DA ESTRELA	3
RC127	BEIRA INTERIOR NORTE	3
RC128	BEIRA INTERIOR SUL	3
RC129	COVA DA BEIRA	3
RC2	**SUL DO CONTINENTE**	1
RC21	LISBOA E VALE DO TEJO	2
RC211	OESTE	3
RC212	GRANDE LISBOA - NORTE	3
RC213	GRANDE LISBOA - SUL	3
RC214	MEDIO TEJO	3
RC215	LEZIRIA DO TEJO	3
RC22	ALENTEJO	2
RC221	ALENTEJO LITORAI	3
RC222	ALTO ALENTEJO	3
RC223	ALENTEJO CENTRAL	3
RC224	BAIXO ALENTEJO	3
C23	ALGARVE	2
RC3	**ILHAS**	1
RC31	ACORES	2
RC32	MADEIRA	2

APPENDIX 2 **NUTS II or UNDIVIDED NUTS I REGIONS in which MORE THAN 1000 km^2 of BARLEY was HARVESTED in 1987**

REGION CODE	REGION NAME	NUTS LEVEL
R11	**SCHLESWIG-HOLSTEIN**	1
R13B	HANNOVER	2
R13C	LUENEBURG	2
R13D	WESER-EMS	2
R221	CHAMPAGNE-ARDENNE	2
R222	PICARDIE	2
R224	CENTRE	2
R226	BOURGOGNE	2
R23	**NORD, PAS-DE-CALAIS**	1
R241	LORRAINE	2
R252	BRETAGNE	2
R253	POITOU-CHARENTES	2
R262	MIDI-PYRENEES	2
R722	NORTH YORKSHIRE	2
R74	**EAST ANGLIA**	1
R7A1	BORDERS, CENTRAL, FIFE, LOTHIAN, TAYSIDE	2
R7A4	GRAMPIAN	2
R8	**IRELAND**	1
R902	OST FOR STOREBAELT, EX.HOVEDST	2
R903	VEST FOR STOREBAELT	2
RB22	NAVARRA	2
RB24	ARAGON	2
RB41	CASTILLA - LEON	2
RB42	CASTILLA - LA MANCHA	2
RB43	EXTREMADURA	2
RB51	CATALUNA	2
RB61	ANDALUCIA	2

APPENDIX 3 **NUTS I, II and III REGIONS in which LESS THAN 100 km^2 of BARLEY was HARVESTED in 1987.**

NB Data are incomplete at the NUTS III level.

REGION CODE	REGION NAME	NUTS LEVEL
R12	**HAMBURG**	**1**
R14	**BREMEN**	**1**
R1A	**SAARLAND**	**1**
R1B	**BERLIN(WEST)**	**1**
R2613	LANDES	3
R283	CORSE	2
R312	VALLE D'AOSTA	2
R313	LIGURIA	2
R331	TRENTINO-ALTO ADIGE	2
R382	MOLISE	2
R412	FRIESLAND	2
R413	DRENTHE	2
R42	**OOST-NEDERLAND**	**1**
R45	**ZUID-NEDERLAND**	**1**
R471	UTRECHT	2
R472	NOORD-HOLLAND	2
R473	ZUID HOLLAND	2
R474	ZEELAND	2
R501	ANTWERPEN	2
R505	LIMBURG	2
R506	LUXEMBOURG	2

REGION CODE	REGION NAME	NUTS LEVEL
R7132	TYNE AND WEAR	3
R7532	SURREY	3
R755	GREATER LONDON	2
R7562	ISLE OF WIGHT	3
R7611	AVON	3
R773	WEST MIDLANDS (COUNTY)	2
R782	GREATER MANCHESTER	2
R784	MERSEYSIDE	2
R7911	CLWYD	
R7913	GWYNEDD	3
R7914	POWYS	3
R792	GWENT, MID-SOUTH-WEST GLAMORGAN	2
R8002	SOUTH WEST	3
R8006	DONEGAL	3
R8009	NORTH WEST	3
RA27	IPEIROS	2
RA36	KRITI	2
RB1	**NOROESTE**	**2**
RB612	CADIZ	3
RB615	HUELVA	3
RB7	**CANARIAS**	**1**
RC11	NORTE	2
RC12	CENTRO	2
RC23	ALGARVE	2
RC3	**ILHAS**	**1**
RC31	ACORES	2
RC32	MADEIRA	2

APPENDIX 4 LAND and BARLEY AREAS by NUTS II REGION

These estimates of land area and of harvested barley area were obtained from the Eurostat regional statistical database. The area of barley in German and Portugese NUTS II regions was estimated using proportions established for those years when a complete regional survey was carried out. Regional figures for the constituent countries of the United Kingdom were derived from data published by the relevant Agricultural Statistics Services. The current NUTS II boundaries for Greece and Portugal differ from the original ones used in this volume. A colon (:) represents missing data, a plus (+) denotes less than 0.5 km^2 and a zero (0) shows that no barley was recorded in the region.

REGION CODE	REGION NAME	LAND AREA (km^2)	BARLEY AREA (km^2) (1985)	(1986)	(1987)	(1988)
R11	Schleswig Holstein	15 721	1 428	1 396	1 276	1 130
R12	Hamburg	755	16	16	14	14
R13A	Braunschweig	8 093	796	794	758	734
R13B	Hannover	9 043	1 100	1 098	1 050	1 003
R13C	Lüneburg	15 346	1 314	1 311	1 228	1 172
R13D	Weser-Ems	14 965	1 337	1 334	1 214	1 160
R14	Bremen	404	5	5	4	4
R151	Düsseldorf	5 288	439	454	412	384
R152	Köln	7 363	478	495	467	435
R153	Münster	6 898	989	1 023	999	930
R154	Detmold	6 515	874	904	905	842
R155	Arnsberg	7 999	494	511	500	466
R16A	Darmstadt	7 446	389	403	372	376
R16B	Giessen	5 381	368	381	363	367
R16C	Kassel	8 288	659	682	647	653
R171	Koblenz	8 092	558	553	529	582
R172	Trier	4 925	318	316	296	326
R173	Rheinhessen-Pfalz	6 830	508	504	458	503
R181	Stuttgart	10 558	819	806	776	827
R182	Karlsruhe	6 919	321	316	299	318
R183	Freiburg	9 357	301	296	280	299
R184	Tübingen	8 917	566	557	548	584

REGION CODE	REGION NAME	LAND AREA (km²)	BARLEY AREA (km²)			
			(1985)	(1986)	(1987)	(1988)
R191	Oberbayern	17 528	897	881	842	870
R192	Neiderbayern	19 332	685	673	652	673
R193	Oberpfalz	9 691	871	855	825	852
R194	Oberfranken	7 231	802	788	765	790
R195	Mittelfranken	7 245	701	688	668	690
R196	Unterfranken	8 531	865	850	791	817
R197	Schwaben	9 994	488	480	461	476
R1A	Saarland	2 571	107	105	100	99
R1B	Berlin (West)	480	+	+	+	+
R21	Ile de France	12 012	585	533	484	491
R221	Champagne-Ardenne	25 606	2 365	2 277	1 959	1 905
R222	Picardie	19 399	1 633	1 723	1 640	1 649
R223	Haute Normandie	12 317	710	710	785	695
R224	Centre	39 151	2 463	1 915	1 710	1 806
R225	Basse Normandie	17 589	436	413	398	390
R226	Bourgogne	31 582	2 310	2 193	1 965	1 812
R23	Nord-Pas de Calais	12 414	1 489	1 555	1 490	1 460
R241	Lorraine	23 547	1 939	1 710	1 748	1 678
R242	Alsace	8 280	279	240	222	179
R243	Franche-Comté	16 202	640	578	573	547
R251	Pays de la Loire	32 082	666	556	521	481
R252	Bretagne	27 208	1 379	1 304	1 345	1 318
R253	Poitou-Charentes	25 810	1 405	1 270	1 140	1 100
R261	Aquitaine	41 308	538	474	456	405
R262	Midi-Pyrénées	45 348	1 488	1 483	1 446	1 461
R263	Limousin	16 942	269	261	227	222
R271	Rhône-Alpes	43 698	761	709	669	624
R272	Auvergne	26 013	644	590	519	494
R281	Languedoc-Rousillon	27 376	195	157	182	166
R282	Provence-Alpes-Côte d'Azur	31 400	353	307	260	274
R283	Corse	8 680	8	9	9	10
R311	Piemonte	25 399	321	302	265	305
R312	Valle d'Aosta	3 2622	0	+	+	+
R313	Liguria	5 416	1	1	2	2
R32	Lombardia	23 857	923	898	838	750

REGION CODE	REGION NAME	LAND AREA (km²)	BARLEY AREA (km²)			
			(1985)	(1986)	(1987)	(1988)
R331	Trentino-Alto Adige	13 620	10	7	7	7
R332	Veneto	18 364	253	146	321	320
R333	Friuli-Venezia Giulia	7 846	174	169	164	120
R34	Emilia-Romagna	22 123	475	413	377	402
R351	Toscana	22 992	211	404	353	377
R352	Umbria	8 456	80	113	110	145
R353	Marche	9 693	220	219	210	226
R36	Lazio	17 203	290	274	214	208
R37	Campania	13 595	102	100	116	122
R381	Abruzzi	10 794	150	156	167	174
R382	Molise	4 438	72	82	78	68
R391	Puglia	19 348	371	317	349	408
R392	Basilicata	9 992	265	258	310	321
R393	Calabria	15 080	142	122	136	122
R3A	Sicilia	25 708	131	130	136	131
R3B	Sardegna	24 090	265	289	294	293
R411	Groningen	2 607	95	129	134	:
R412	Friesland	3 790	8	8	10	:
R413	Drenthe	2 681	16	27	32	:
R421	Overijssel	3 420	3	3	6	:
R422	Gelderland	5 144	16	16	20	:
R423	Flevoland	2 116	47	63	52	:
R451	Noord Brabant	5 106	39	31	50	:
R452	Limburg	2 208	45	42	50	:
R471	Utrecht	1 402	1	1	1	:
R472	Noord-Holland	2 958	12	13	29	:
R473	Zuid-Holland	3 363	33	30	42	:
R474	Zeeland	3 017	71	56	77	:
R501	Antwerpen	2 867	8	9	10	11
R502	Brabant	3 358	242	265	269	260
R503	Hainaut	3 786	209	228	222	211
R504	Liège	3 862	153	172	164	158
R505	Limburg	2 422	72	76	77	77
R506	Luxembourg	4 440	76	75	66	62
R507	Namur	3 666	199	220	206	200
R508	Oost-Vlaanderen	2 982	109	111	104	103
R509	West-Vlaanderen	3 135	113	123	111	121

REGION CODE	REGION NAME	LAND AREA (km²)	BARLEY AREA (km²)			
			(1985)	(1986)	(1987)	(1988)
R6	Luxembourg (Grand Duché)	2 586	170	181	169	170
R711	Cleveland, Durham	3 019	278	272	257	:
R712	Cumbria	6 810	243	237	224	:
R713	Northumberland, Tyne & Wear	5 572	490	478	452	:
R721	Humberside	3 512	749	709	676	:
R722	North Yorks.	8 309	1 117	1 057	1 007	:
R723	South Yorks.	1 560	185	176	167	:
R724	West Yorks.	2 039	126	119	113	:
R731	Derbyshire, Notts.	4 795	577	549	515	:
R732	Leics., Northants.	4 920	634	604	567	:
R733	Lincolnshire	5 915	897	854	801	:
R74	East Anglia	12 573	2 290	2 109	2 042	:
R751	Beds., Herts.	2 869	369	355	339	:
R752	Berks., Bucks., Oxon.	5 750	853	819	782	:
R753	East & West Sussex, Surrey	5 463	357	343	327	:
R754	Essex	3 672	431	414	395	:
R755	Greater London	1 579	21	21	20	:
R756	Hampshire, Isle of Wight	4 158	524	503	480	:
R757	Kent	3 731	299	287	274	:
R761	Avon, Gloucs., Wilts.	7 470	905	910	909	:
R762	Cornwall, Devon	10 275	863	868	867	:
R763	Dorset, Somerset	6 105	412	414	413	:
R771	Hereford, Worcs., Warwickshire	5 907	621	629	608	:
R772	Salop, Staffs.	6 206	743	753	727	:
R773	West Midlands (County)	899	34	34	33	:
R781	Cheshire	2 328	207	197	193	:
R782	Greater Manchester	1 287	49	47	46	:
R783	Lancashire	3 063	143	137	134	:
R784	Merseyside	652	77	74	72	:
R791	Clwyd, Dyfed, Gwynedd, Powys	17 141	418	420	425	422
R792	Gwent, Glamorgan	3 627	86	85	89	92
R7A1	Borders, Central, Fife, Lothian, Tayside	18 124	2 009	2 051	1 882	1 925
R7A2	Dumfries, Galloway, Strathclyde	20 204	536	507	480	454
R7A3	Highlands, Islands	31 703	304	308	281	278
R7A4	Grampian	8 752	1 308	1 316	1 224	1 229
R7B	Northern Ireland	14 120	470	485	444	423
R8	Ireland	68 895	2 984	2 828	2 760	2 660

REGION CODE	REGION NAME	LAND AREA (km²)	BARLEY AREA (km²)			
			(1985)	(1986)	(1987)	(1988)
R901	Hovedstadsregionen	2 857	527	496	432	547
R902	Ost for Storebaelt (excl. R901)	6 970	1 998	1 834	1 715	2 072
R903	Vest for Storebaelt	33 253	8 412	8 451	7 284	9 021
RA12	Kentriki & Dytiki Makedonia	24 630	1 175	950	837	:
RA14	Thessalia	13 929	494	457	401	:
RA15	Anatoliki Makedonia	9 547	369	293	266	:
RA18	Thraki	8 578	191	157	146	:
RA21	Anatoliki Sterea & Nisia	22 033	479	422	395	:
RA23	Peloponnisos & Dytiki Sterea	28 227	221	202	192	:
RA27	Ipeiros	10 169	11	9	8	:
RA36	Kriti	8 336	52	46	41	:
RA39	Nisia Anatolikou Aigaiou	6 541	129	127	124	:
RB11	Galicia	29 434	18	18	19	22
RB12	Asturias	10 565	0	0	0	0
RB13	Cantabria	5 298	4	4	4	3
RB21	Pais Vasco	7 261	214	225	213	185
RB22	Navarra	10 421	1 250	1 275	1.394	1 384
RB23	Rioja	5 034	487	478	475	458
RB24	Aragon	47 650	6 643	6 578	7 059	6 666
RB3	Madrid	7 995	508	456	447	410
RB41	Castilla-Leon	94 193	15 439	15 660	15 374	14294
RB42	Castilla-La Mancha	79 230	9 527	9 967	10 382	10 110
RB43	Extremadura	41 602	1 390	1 435	1 307	1 170
RB51	Cataluña	31 930	2 262	2 327	2 371	2 418
RB52	Comunidad Valenciana	23 305	223	224	239	223
RB53	Baleares	5 014	233	233	231	220
RB61	Andalucia	87 268	3 550	3 699	3 608	3 183
RB62	Murcia	11 317	700	816	877	1 000
RB63	Ceuta y Melilla	31	0	0	0	0
RB7	Canarias	7 242	8	8	5	7
RC11	Norte	21 194	33	33	33	28
RC12	Centro	23 270	32	32	33	27
RC21	Lisboa e Vale do Tejo	13 194	183	185	187	158
RC22	Alentejo	26 091	560	569	574	482
RC23	Algarve	4 960	52	52	53	44
RC31	Acores	2 247	:	:	:	:
RC32	Madeira	794	:	:	:	:

APPENDIX 5 **NUTS REGIONS Making up the BARLEY GROWING AREAS of the EC.**

BARLEY AREA	REGION CODE	REGION NAME	NUTS LEVEL
A	R712	CUMBRIA	2
	R7A2	DUMFRIES AND GALLOWAY, STRATHCLYDE	2
	R7B	NORTHERN IRELAND	1
	R8	REPUBLIC OF IRELAND	0
	R78	NORTH WEST (ENGLAND)	1
	R791	CLWYD, DYFED, GWYNEDD, POWYS	2
B	R7A1	BORDERS-CENTRAL-FIFE-LOTHIAN-TAYSIDE	2
	R7A3	HIGHLANDS, ISLANDS	2
	R7A4	GRAMPIAN	2
	R711	CLEVELAND, DURHAM	2
	R713	NORTHUMBERLAND, TYNE AND WEAR	2
C	R72	YORKSHIRE AND HUMBERSIDE	1
	R73	EAST MIDLANDS	1
	R71	NORTH	1
	R761	AVON, GLOUCESTERSHIRE, WILTSHIRE	2
	R77	WEST MIDLANDS	
D	R9	DENMARK	
	R11	SCHLESWIG HOLSTEIN	1
	R12	HAMBURG	1
E	R74	EAST ANGLIA	1
	R75	SOUTH EAST	1
F	R23	NORD, PAS DE CALAIS	1
	R222	PICARDIE	2
	R4	NEDERLAND	0
	R501	ANTWERPEN	2
	R502	BRABANT	2
	R503	HAINAUT	2
	R505	LIMBURG	2
	R508	OOST-VLAANDEREN	2
	R509	WEST-VLAANDEREN	2

BARLEY AREA	REGION CODE	REGION NAME	NUTS LEVEL
G	**R13**	**NIEDERSACHEN**	**1**
	R14	**BREMEN**	**1**
	R15	**NORDRHEIN-WESTFALEN**	**1**
	R1B	**BERLIN (WEST)**	**1**
H	R792	GWENT, GLAMORGAN	2
	R762	CORNWALL, DEVON	2
	R763	DORSET, SOMERSET	2
	R223	HAUTE-NORMANDIE	2
	R225	BASSE-NORMANDIE	2
	R251	PAYS DE LA LOIRE	2
	R252	BRETAGNE	2
I	**R1A**	**SAARLAND**	**1**
	R21	**ILE DE FRANCE**	**1**
	R221	CHAMPAGNE-ARDENNE	2
	R224	CENTRE	2
	R226	BOURGOGNE	2
	R24	**EST**	**1**
	R6	**LUXEMBOURG (GRAND DUCHE)**	**0**
J	R504	LIEGE	2
	R506	LUXEMBOURG	2
	R507	NAMUR	2
	R16	**HESSEN**	**1**
	R17	**RHEINLAND-PFALZ**	**1**
	R18	**BADEN-WUERTTEMBERG**	**1**
K	**R19**	**BAYERN**	**1**
L	**RB1**	**NOROESTE**	**1**
	RC11	NORTE	2
M	R25	POITOU-CHARENTES	2
	R26	**SUD-OUEST**	**1**
	R27	**CENTRE-EST**	**1**

BARLEY AREA	REGION CODE	REGION NAME	NUTS LEVEL
N	R28	MEDITERRANEE	1
	R31	NORD OVEST	1
	R32	LOMBARDIA	1
	R33	NORD EST	1
	R34	EMILIA-ROMAGNA	1
O	RB41	CASTILLA - LEON	2
	RB2	NORESTE	1
P	RC12	CENTRO	2
	RC2	SUL DO CONTINENTE	1
	RB6	SUR	1
Q	RB3	MADRID	1
	RB42	CASTILLA-LA MANCHA	2
	RB43	EXTREMADURA	2
R	RB5	ESTE	1
S	R35	CENTRO	1
	R36	LAZIO	1
	R37	CAMPANIA	1
	R38	ABRUZZI-MOLISE	1
	R3B	SARDEGNA	1
T	RA	GREECE	0
	R39	SUD	1
	R3A	SICILIA	1
U	RC3	ILHAS	1
	RB7	CANARIAS	1

APPENDIX 6 BARLEY YIELDS by NUTS II REGION

These yield estimates from the Eurostat regional statistical database were obtained by dividing production by harvested area. Consequently, as pointed out in section 4.7 of this volume, these figures should be treated with caution. Yields have been calculated without taking account of date of sowing. Yields from spring-sown crops are approximately 85% of those from autumn-sown ones. Where data at the NUTS II level were not available, figures for the corresponding NUTS I or NUTS 0 regions (bracketed figures) have been used. Greek and Portugese NUTS boundaries were altered between 1983 and 1988 but some regional estimates have been included to indicate the geographical variation of yield in these countries. A colon (:) represents missing data and a zero (0) shows that no barley was recorded in the region.

REGION CODE	REGION NAME	YIELD ($t\ ha^{-1}$) (1983)	(1984)	(1985)	(1986)	(1987)	(1988)
R11	Schleswig Holstein	5.4	6.0	5.4	6.1	5.8	6.6
R12	Hamburg	4.9	5.3	5.2	5.5	5.4	5.9
R13A	Braunschweig	5.2	(4.8)	(4.8)	(5.0)	5.3	(4.8)
R13B	Hannover	4.9	(4.8)	(4.8)	(5.0)	5.3	(4.8)
R13C	Lüneburg	3.9	(4.8)	(4.8)	(5.0)	4.7	(4.8)
R13D	Weser-Ems	3.8	(4.8)	(4.8)	(5.0)	4.4	(4.8)
R14	Bremen	4.5	4.9	0	0	0	0
R151	Düsseldorf	5.0	(5.6)	(5.2)	(5.5)	5.2	(5.6)
R152	Köln	5.4	(5.6)	(5.2)	(5.5)	5.5	(5.6)
R153	Münster	4.6	(5.6)	(5.2)	(5.5)	4.9	(5.6)
R154	Detmold	4.7	(5.6)	(5.2)	(5.5)	5.2	(5.6)
R155	Arnsberg	4.8	(5.6)	(5.2)	(5.5)	4.9	(5.6)
R16A	Darmstadt	4.3	(5.3)	(5.0)	(5.0)	4.6	(5.4)
R16B	Giessen	4.4	(5.3)	(5.0)	(5.0)	4.6	(5.4)
R16C	Kassel	4.9	(5.3)	(5.0)	(5.0)	4.8	(5.4)
R171	Koblenz	3.9	(4.7)	(4.6)	(4.5)	4.3	(4.7)
R172	Trier	3.2	(4.7)	(4.6)	(4.5)	4.0	(4.7)
R173	Rheinhessen-Pfalz	3.5	(4.7)	(4.6)	(4.5)	4.3	(4.7)
R181	Stuttgart	4.1	(4.8)	(4.7)	(3.9)	4.3	(5.1)
R182	Karlsruhe	3.8	(4.8)	(4.7)	(3.9)	4.3	(5.1)
R183	Freiburg	4.0	(4.8)	(4.7)	(3.9)	4.1	(5.1)
R184	Tübingen	4.5	(4.8)	(4.7)	(3.9)	4.2	(5.1)
R191	Oberbayern	4.6	(5.1)	(5.0)	(4.2)	4.3	(5.2)
R192	Neiderbayern	4.9	(5.1)	(5.0)	(4.2)	4.4	(5.2)
R193	Oberpfalz	3.9	(5.1)	(5.0)	(4.2)	3.7	(5.2)
R194	Oberfranken	3.4	(5.1)	(5.0)	(4.2)	3.4	(5.2)
R195	Mittelfranken	4.0	(5.1)	(5.0)	(4.2)	4.0	(5.2)
R196	Unterfranken	4.1	(5.1)	(5.0)	(4.2)	4.3	(5.2)

REGION CODE	REGION NAME	YIELD (t ha^{-1}) (1983)	(1984)	(1985)	(1986)	(1987)	(1988)
R197	Schwaben	4.7	(5.1)	(5.0)	(4.2)	4.4	(5.2)
R1A	Saarland	3.1	4.5	4.4	4.1	4.2	4.5
R1B	Berlin (West)	2.7	3.6	0	0	0	0
R21	Ile de France	4.8	6.5	6.2	5.7	6.4	6.3
R221	Champagne-Ardenne	4.8	6.4	6.0	5.6	6.1	6.1
R222	Picardie	5.9	7.1	6.8	7.1	6.6	7.1
R223	Haute Normandie	5.8	7.0	6.6	6.7	6.3	7.1
R224	Centre	3.9	5.6	4.9	4.6	5.8	5.7
R225	Basse Normandie	4.6	5.8	5.5	5.75	.7	5.9
R226	Bourgogne	3.3	5.1	4.8	4.0	4.9	4.6
R23	Nord-Pas de Calais	5.9	7.1	6.0	6.8	6.0	7.0
R241	Lorraine	3.2	5.2	4.8	4.1	4.1	5.0
R242	Alsace	3.6	5.3	4.9	3.9	4.7	5.2
R243	Franche-Comté	1.8	5.0	4.5	3.0	4.3	4.1
R251	Pays de la Loire	3.7	4.7	4.6	4.7	5.1	4.9
R252	Bretagne	3.8	5.0	4.7	5.1	5.2	5.2
R253	Poitou-Charentes	3.7	4.7	4.7	4.2	5.0	4.3
R261	Aquitaine	3.7	3.9	3.7	3.4	4.0	3.1
R262	Midi-Pyrénées	3.8	4.5	4.4	4.1	4.7	3.7
R263	Limousin	2.1	3.0	2.9	1.9	3.2	2.7
R271	Rhône-Alpes	3.0	4.6	4.0	3.2	4.7	4.0
R272	Auvergne	3.0	. 4.0	4.1	2.8	4.4	3.7
R281	Languedoc-Rousillon	2.8	3.4	3.4	2.8	3.6	3.0
R282	Provence-Alpes-Côte d'Azur	3.6	3.9	3.5	2.7	3.3	3.3
R283	Corse	3.5	2.0	2.9	3.3	3.5	3.6
R311	Piemonte	3.9	4.1	4.1	3.4	5.0	3.5
R312	Valle d'Aosta	2.0	:	:	2.0	1.9	2.0
R313	Liguria	2.3	:	2.0	3.6	2.7	2.6
R32	Lombardia	5.1	5.5	4.7	4.5	6.1	5.0
R331	Trentino-Alto Adige	1.6	1.2	1.2	1.7	1.7	1.7
R332	Veneto	4.9	5.2	5.0	8.2	5.5	5.0
R333	Friuli-Venezia Giulia	3.9	4.3	4.3	4.3	4.4	4.6
R34	Emilia-Romagna	4.7	4.9	4.7	4.5	5.4	4.5
R351	Toscana	2.6	2.8	2.5	2.6	3.1	2.5
R352	Umbria	2.6	2.9	3.0	4.0	3.4	3.3
R353	Marche	3.0	3.3	3.2	3.6	4.0	3.8
R36	Lazio	2.9	3.5	2.7	3.1	3.2	3.2
R37	Campania	2.3	2.5	2.4	3.0	2.8	2.7
R381	Abruzzi	2.2	2.6	2.7	2.7	2.7	2.7
R382	Molise	1.6	2.6	3.0	3.0	3.1	3.0
R391	Puglia	1.4	2.5	2.3	2.6	1.9	2.5
R392	Basilicata	1.0	2.5	1.9	2.4	2.3	2.6
R393	Calabria	1.0	1.7	1.7	1.7	1.6	1.9

REGION CODE	REGION NAME	YIELD (t ha^{-1}) (1983)	(1984)	(1985)	(1986)	(1987)	(1988)
R3A	Sicilia	1.5	1.9	1.8	1.7	1.7	1.0
R3B	Sardegna	1.1	2.1	1.5	2.0	1.0	2.3
R411	Groningen	4.7	5.8	5.2	6.6	5.1	:
R412	Friesland	3.6	5.7	5.1	6.1	5.4	:
R413	Drenthe	3.8	4.0	5.1	5.5	4.8	:
R421	Overijssel	4.7	4.3	4.3	5.4	5.2	:
R422	Gelderland	3.1	5.2	5.0	5.2	5.3	:
R423	Flevoland	6.1	5.1	4.1	6.2	4.9	:
R451	Noord Brabant	5.2	5.9	5.2	6.1	5.2	:
R452	Limburg	4.6	5.7	4.8	5.2	5.2	:
R471	Utrecht	3.7	4.9	4.6	4.6	4.7	:
R472	Noord-Holland	4.6	5.6	5.2	6.6	5.2	:
R473	Zuid-Holland	5.1	5.8	5.2	6.6	5.1	:
R474	Zeeland	5.1	6.4	5.8	6.8	5.7	:
R501	Antwerpen	3.7	4.1	3.9	4.1	3.9	4.2
R502	Brabant	4.9	6.8	6.1	6.6	5.6	6.7
R503	Hainaut	5.3	6.6	6.1	6.6	6.3	6.6
R504	Liège	5.4	7.2	6.5	6.9	6.1	7.0
R505	Limburg	4.8	6.4	5.7	6.3	5.5	5.8
R506	Luxembourg	2.6	4.4	3.9	3.7	3.4	4.3
R507	Namur	4.7	6.4	6.1	5.9	5.5	6.0
R508	Oost-Vlaanderen	4.7	5.7	5.0	5.6	4.6	5.3
R509	West-Vlaanderen	4.8	6.2	5.7	6.4	5.5	5.5
R6	Luxembourg (Grand Duche)	2.2	3.9	3.6	3.6	3.6	3.8
R711	Cleveland, Durham	(4.2)	(5.6)	(4.9)	(5.4)	(4.9)	:
R712	Cumbria	(4.2)	(5.6)	(4.9)	(5.4)	(4.9)	:
R713	Northumberland, Tyne & Wear	(4.2)	(5.6)	(4.9)	(5.4)	(4.9)	:
R721	Humberside	(4.8)	(5.8)	(5.6)	(5.6)	(5.4)	:
R722	North Yorks.	(4.8)	(5.8)	(5.6)	(5.6)	(5.4)	:
R723	South Yorks.	(4.8)	(5.8)	(5.6)	(5.6)	(5.4)	:
R724	West Yorks.	(4.8)	(5.8)	(5.6)	(5.6)	(5.4)	:
R731	Derbyshire, Notts.	(4.8)	(5.9)	(5.3)	(5.4)	(5.2)	:
R732	Leics., Northants.	(4.8)	(5.9)	(5.3)	(5.4)	(5.2)	:
R733	Lincolnshire	(4.8)	(5.9)	(5.3)	(5.4)	(5.2)	:
R74	East Anglia	4.8	5.6	4.9	5.1	4.9	:
R751	Beds., Herts.	(4.8)	(5.8)	(5.3)	(5.4)	(5.2)	:
R752	Berks., Bucks., Oxon.	(4.8)	(5.8)	(5.3)	(5.4)	(5.2)	:
R753	East & West Sussex, Surrey	(4.8)	(5.8)	(5.3)	(5.4)	(5.2)	:
R754	Essex	(4.8)	(5.8)	(5.3)	(5.4)	(5.2)	:
R755	Greater London	(4.8)	(5.8)	(5.3)	(5.4)	(5.2)	:
R756	Hampshire, Isle of Wight	(4.8)	(5.8)	(5.3)	(5.4)	(5.2)	:
R757	Kent	(4.8)	(5.8)	(5.3)	(5.4)	(5.2)	:

REGION CODE	REGION NAME	YIELD (t ha^{-1}) (1983)	(1984)	(1985)	(1986)	(1987)	(1988)
R761	Avon, Gloucs., Wilts.	(4.8)	(5.6)	(5.1)	(5.1)	(5.1)	:
R762	Cornwall, Devon	(4.8)	(5.6)	(5.1)	(5.1)	(5.1)	:
R763	Dorset, Somerset	(4.8)	(5.6)	(5.1)	(5.1)	(5.1)	:
R771	Hereford, Worcs., Warwickshire	(4.6)	(5.6)	(5.1)	(5.7)	(5.4)	:
R772	Salop, Staffs.	(4.6)	(5.6)	(5.1)	(5.7)	(5.4)	:
R773	West Midlands (County)	(4.6)	(5.6)	(5.1)	(5.7)	(5.4)	:
R781	Cheshire	(3.9)	(5.1)	(4.6)	(4.8)	(4.4)	:
R782	Greater Manchester	(3.9)	(5.1)	(4.6)	(4.8)	(4.4)	:
R783	Lancashire	(3.9)	(5.1)	(4.6)	(4.8)	(4.4)	:
R784	Merseyside	(3.9)	(5.1)	(4.6)	(4.8)	(4.4)	:
R791	Clwyd, Dyfed, Gwynedd, Powys	(4.1)	(5.3)	(4.6)	(4.9)	(4.7)	:
R792	Gwent, Glamorgan	(4.1)	(5.3)	(4.6)	(4.9)	(4.7)	:
R7A1	Borders, Central, Fife, Lothian, Tayside	4.7	5.5	4.8	5.1	5.2	4.9
R7A2	Dumfries, Galloway, Strathclyde	4.2	5.0	3.2	4.0	4.5	4.2
R7A3	Highlands, Islands	4.9	5.0	4.5	5.6	4.7	4.4
R7A4	Grampian	4.4	5.5	4.2	5.2	4.5	4.2
R7B	Northern Ireland	4.3	4.8	3.4	4.0	4.5	
R8	Ireland	4.8	5.8	5.0	5.0	5.8	6.0
R901	Hovedstadsregionen	3.8	5.6	5.1	4.8	4.6	:
R902	Ost for Storebaelt (excl. R901)	4.3	6.0	5.6	5.5	5.1	:
R903	Vest for Storebaelt	3.1	4.9	4.6	4.6	4.4	:
RA12	Kentriki & Dytiki Makedonia	1.8	2.3	1.9	2.5	(2.4)	(2.5)
RA14	Thessalia	2.5	3.1	2.4	4.0	(2.4)	(2.5)
RA15	Anatoliki Makedonia	1.6	2.4	1.5	2.5	(2.4)	(2.5)
RA18	Thraki	2.4	2.4	2.3	2.7	(2.4)	(2.5)
RA21	Anatoliki Sterea & Nisia	1.7	2.1	2.0	1.8	(2.4)	(2.5)
RA23	Peloponnisos & Dytiki Sterea	1.5	1.6	1.6	1.8	(2.4)	(2.5)
RA27	Ipeiros	1.7	1.6	2.0	1.6	(2.4)	(2.5)
RA36	Kriti	1.3	1.5	1.6	1.5	(2.4)	(2.5)
RA39	Nisia Anatolikou Aigaiou	1.4	1.5	1.4	1.6	(2.4)	(2.5)
RB11	Galicia	1.7	1.8	1.7	1.6	1.7	:
RB12	Asturias	0	0	0	0	0	:
RB13	Cantabria	2.3	2.4	2.0	1.2	2.0	:
RB21	Pais Vasco	3.3	4.0	4.4	3.1	3.1	:
RB22	Navarra	3.0	3.3	3.3	2.2	2.8	:
RB23	Rioja	3.2	3.9	4.0	2.1	2.6	:
RB24	Aragon	1.4	2.7	2.3	1.9	2.0	:
RB3	Madrid	1.1	2.8	2.6	2.0	2.1	:
RB41	Castilla-Leon	2.5	2.8	2.7	1.6	2.7	:
RB42	Castilla-La Mancha	1.3	2.4	2.4	1.6	1.8	:
RB43	Extremadura	0.9	2.4	1.9	1.6	2.1	:

REGION CODE	REGION NAME	YIELD (t ha^{-1}) (1983)	(1984)	(1985)	(1986)	(1987)	(1988)
RB51	Cataluña	1.5	3.5	3.3	2.2	2.7	:
RB52	Communidad Valenciana	0.8	2.3	2.3	1.7	2.1	:
RB53	Baleares	0.4	1.0	1.1	1.0	1.1	:
RB61	Andalucia	1.0	2.4	2.0	1.6	1.5	:
RB62	Murcia	0.6	0.9	1.0	1.6	1.2	:
RB63	Ceuta y Melilla	0	0	0	0	0	:
RB7	Canarias	0.4	0.8	0.9	2.1	1.2	:
RC11	Norte	(0.7)	(1.1)	(0.8)	0.6	(1.0)	(0.7)
RC12	Centro	(0.7)	(1.1)	(0.8)	0.7	(1.0)	(0.7)
RC21	Lisboa e Vale do Tejo	(0.7)	(1.1)	(0.8)	0.9	(1.0)	(0.7)
RC22	Alentejo	(0.7)	(1.1)	(0.8)	1.1	(1.0)	(0.7)
RC23	Algarve	(0.7)	(1.1)	(0.8)	0.6	(1.0)	(0.7)
RC31	Acores	(0.7)	(1.1)	(0.8)	:	(1.0)	(0.7)
RC32	Madeira	(0.7)	(1.1)	(0.8)	:	(1.0)	(0.7)

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EUR 13040 — Barley Knowledge Base

G. Russell

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Precise and up-to-date information on agricultural production is a vital component in running market economies. To obtain rapid information, the E.C. Commission has set up a Pilot Project to introduce remote sensing into the European Community agricultural statistics system. Its results will form part of the "Advanced System of Information on Agriculture". This system will depend mainly on remote sensing data from high and low resolution captors but also on methods of interpretation such as agrometeorological models. Part of the activities of the Pilot Project relate thus to the development of agrometeorological models for the regional monitoring of crop state and for quantitative yield predictions on a national scale.

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— physiological and environmental requirements of the crop;
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