



Crop Production in the East of Scotland

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Crop
Production
**in the East of
Scotland**

A Handbook Compiled by
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for the Workshop: **Crop Production under Cool Long Days**, held at Newbattle Abbey College, near Edinburgh, in August 2000, as a Satellite of the 3rd International Crop Science Congress in Hamburg.

Sponsored by



SCOTTISH EXECUTIVE

Rural Affairs Department

EDINBURGH: SCOTTISH AGRICULTURAL SCIENCE AGENCY
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First Published 2000

ISBN No. 1-84268-012-9

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Acknowledgements

The compilers are grateful to Simon Oxley and Andy Evans of SAC, for information on crop protection (Chapter 5); to Ian Anderson of RAD, John Hillman of SCRI, Donald MacKerron of SCRI, Keith Smith of the University of Edinburgh, and Kerr Walker of SAC for reading the final draft text very thoroughly at short notice; and to the Rural Affairs Department of the Scottish Executive for financial assistance in the printing of this booklet. The British Geological Survey kindly provided the original for Figure 3.1. The photographs are from the SASA collection maintained by Sylvia Breslin.

Preface

In April 2000, I launched a discussion document, inviting all interested parties to consider “A Forward Strategy for Scottish Agriculture”, and to deliver their views to me at the Rural Affairs Department not later than 22 September. It is clear to me that, at a time when the Scottish rural economy faces such a range of threats and opportunities, it is important to evaluate all of the relevant strengths and weaknesses, and to be adventurous in exploring possible strategies.

I, therefore, welcome this more detailed analysis of the cropping side of Scottish Agriculture, and I will be interested to receive a full report of the proceedings of the scientific workshop “Crop Production under Cool Long Days” as part of the consultation.

In the contexts of strategy and change, it is significant that the workshop is to be held at Newbattle Abbey: eight hundred years ago, the monks of the Cistercian order, who were probably the world leaders in agricultural technology of their time, first introduced intensive arable agriculture and livestock production to Southern Scotland. Successive abbots of Newbattle, who controlled much of the best land of the Lothians, brought about dramatic changes in land use whose traces survive to today.

I wish you a successful and profitable workshop.

Ross Finnie
Minister for Rural Affairs

1. INTRODUCTION



Winter Wheat on alluvial soil (former saltmarshes),
Duffus Castle, near Forres, Laich of Moray

In Northern Europe, there are substantial agricultural areas north of 55°N which, owing to the warming influence of the North Atlantic Drift, experience cool (not cold) long days during the growing season, and the absence of severe stress. For example, in Scotland, temperatures during the growing season are generally below 20°C, and photoperiod exceeds 15h for at least 5 months. These factors, and a generally high plant health status, can combine to give very high yields of adapted species. Although not very extensive on a global scale, these productive areas could, and should, make an important contribution to the increased levels of crop production which will be needed to support a greatly-increased world population in the 21st century. On the other hand, the progressive effects of global climatic change may have a serious impact on productivity; and there will, undoubtedly, be major changes in the conditions of regional and world trade.

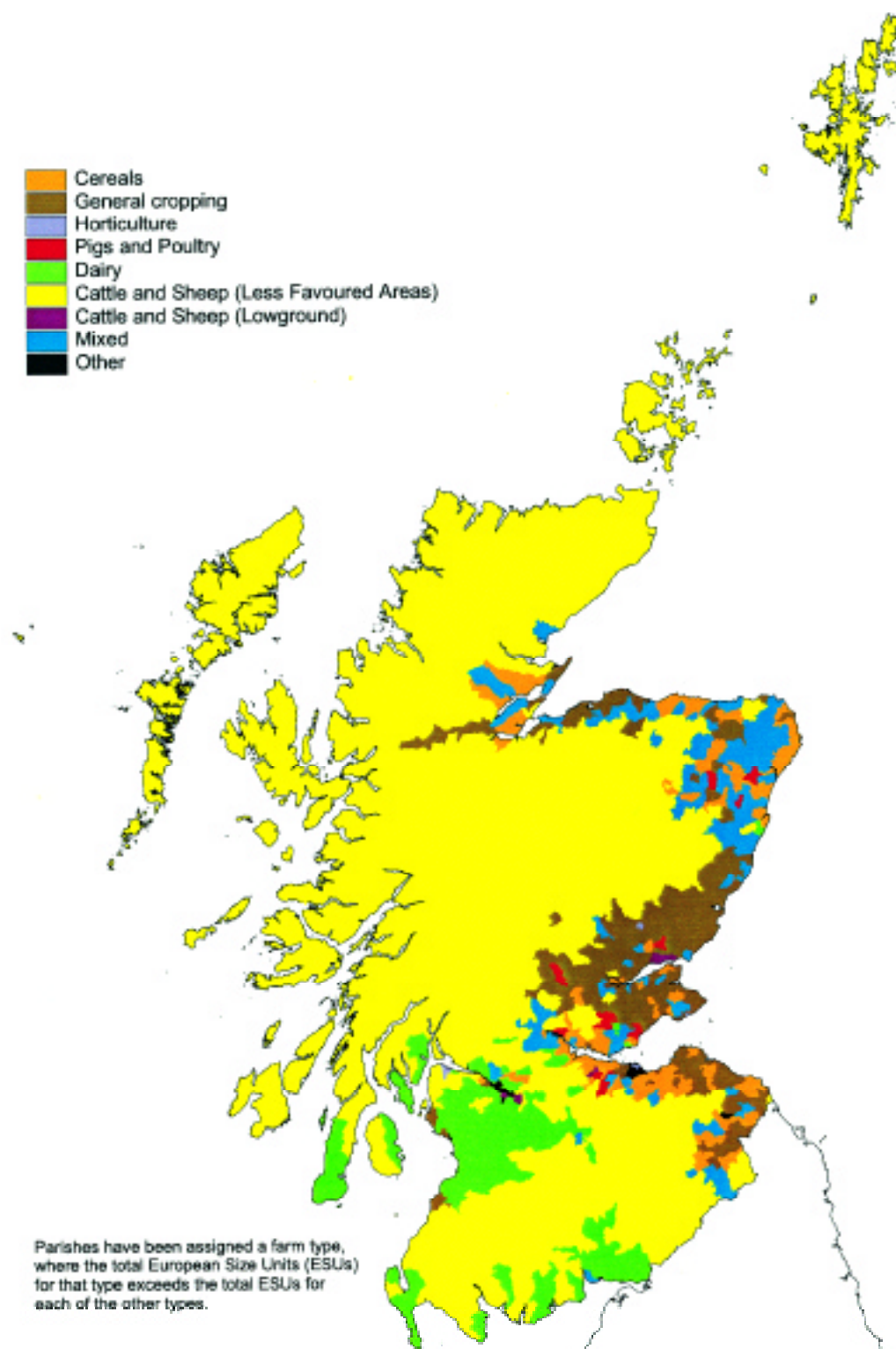
The ICSC Satellite Workshop on “Crop Production under Cool Long Days” at Newbattle in August 2000, was planned to stimulate discussion and study of strategies for the future use of such areas, taking the East of Scotland as a case-study, and to explore the roles crop scientists might play in these strategies. Although this handbook was initially compiled to provide a context for the workshop, and to ensure that delegates could make good use of the day visit, it was intended from the outset that it should be used more widely as an introduction to the cropping systems of the area.

The East of Scotland: The Scope of the Handbook

We have chosen to concentrate on the near-continuous coastal strip from the English Border to Inverness, with a landward boundary where the mean annual rainfall exceeds 1200 mm (Francis, 1981; Figure 1.1). In 1997, this geographic area supported 94.4% of the total arable cropping area of Scotland, 90.2% of the set-aside, and 46.2% of the improved grassland (Table 4.2). The total area of land studied here exceeds 1 million ha. The other economically-important areas of arable cropping in Scotland are mainly in Orkney, Caithness, Easter Ross and Ayrshire, but these represent a small fraction of overall production.

Starting from the English Border, the valley of the Tweed (the Merse) is separated from the lowlands of East Lothian by the Lammermuir Hills which reach the coast near Dunbar. The strip of arable agriculture continues through Mid- and West Lothian, with a limited extension westwards along the Midland Valley. Northwards lie the

Figure 1.1 The distribution of predominant farm types in Scotland by parish; the best arable areas are mapped as "general cropping" or horticulture



from: A Forward Strategy for Scottish Agriculture, Scottish Executive, Edinburgh, 2000

“heartlands” of Fife, Perth and Stirling, with wide river valleys; here the carselands (recent estuarine deposits, in some areas stripped of lowland peat) are a major feature. The coastal strip develops into a wedge through the red soils of Angus and the Mearns (Kincardine), reaching its narrowest point around Stonehaven where the Grampian Mountains meet the North Sea. North of Aberdeen, arable cropping is distributed through the essentially livestock-producing areas of Banff and Buchan, where the Aberdeen Angus breed of cattle originated; but there is one last extensive area of arable land between Elgin and Nairn (the Laich, or sheltered land, of Moray) in the rainshadow of the mountains of the West and Northern Highlands.

As we shall see in Chapter 4, the principal products of Scottish arable farms are barley (for livestock feed and malting), wheat (principally used for the production of grain spirits) and grass (in the form of silage or grazing), with significant areas of oilseed rape and potatoes (seed and ware). There are also small areas of specialist crops such as soft fruit, vegetables and oats for human consumption.

Similar Areas Elsewhere in the World

To place Scotland in a global context, Table 1.1 presents data from a range of other countries experiencing cool long days (boundary set at 55°N). There are no comparable areas in the southern hemisphere. It should be noted that cereal yields in Scotland and Fenno-Scandinavia are well above the world mean. The figures for Estonia, Latvia and Lithuania are for countries in economic transition, and are considerably below their potential.

Brief History of the Agriculture of Lowland Scotland

The recent history of agriculture in the UK, including Scotland, has been dominated by the Common Agricultural Policy of the European Union, which is evolving at present under “Agenda 2000”. Nevertheless, some aspects of Scottish agriculture, notably its farm structure, land tenure, rural population density and the extent of forest cover, cannot be understood without understanding its

Table 1.1 Mean yields of all cereals in areas experiencing “Cool Long Days” (t/ha at 15% dm)

Country	1994-96	1984-86	1974-76
Scotland	6.91	6.08	3.95
Norway	3.81	3.91	3.08
Sweden	4.40	4.06	3.69
Denmark	5.93	5.18	3.71
Finland	3.48	2.97	2.58
Estonia	1.76		
Latvia	1.85		
Lithuania	2.02		
Mean	3.77	4.44	3.40
World Mean	2.82	2.55	1.87

Source : United Nations, Food and Agricultural Organisation Production Yearbooks

history. As this history is distinctly different from that of other European countries, a brief guide follows.

Origins

Scotland was entirely encased in ice up to 20,000 years ago, and the land surface was not finally exposed for a further 10,000 years. Some important arable areas, for example the Laich of Moray and the carselands of Perth and Stirling, did not fully emerge from the sea until around 1,000 years ago, as a result of the slow rebound of surfaces depressed by huge weights of ice. As no soils from previous interglacial periods survive, virtually all of the soils of Scotland date from around 10,000 years ago (Chapter 3).

As the climate improved, the advance of vegetation culminated in dense forest and scrub (varying proportions of birch, pine, hazel and oak, depending on habitat, with alder and willows in wet areas). The early hunters would have had little impact on the environment but, by the start of the Second Millennium BC, a surprisingly sophisticated neolithic society (fine gold jewellery, elaborate pottery and complex funerary arrangements) had emerged in the lowlands of Scotland; these people were at least partly sedentary and partly dependent upon small-scale cropping of cereals and fibres, and livestock rearing. They were attracted by light, well-drained soils, particularly in treeless areas such as Orkney but, on the mainland, they began the onerous work of felling the forest and clearing stones and boulders. Later neolithic/Bronze Age achievements, notably megalithic building (e.g. Maes Howe) and complex stone circles (e.g. at Callanish), show that there was a continuing surplus of food beyond subsistence needs.

Up to the medieval period, the rate of progress in clearing the forest and

cultivating the soil of the lowlands depended upon a variety of factors (e.g. slowed by cooler, wetter conditions around 1,000BC; accelerated by the advent of iron tools around 500BC; interrupted by periods of warfare). By 1200AD, it is likely that most of the potentially-productive lowlands of the East of Scotland had been cleared of forest. The uplands also began to lose their forest cover at that time owing to the intensive sheep rearing introduced by the monasteries; grazing pressure and timber exploitation over the following 500 years ensured that virtually all of the native woodland in the study area disappeared. The areas of arable agriculture (more intensively-cultivated infield, and outfield, with complex subdivisions to ensure fair distribution of land among tenants), devoted to the production of barley and oats for direct human consumption, were islands of cultivation in a wider sea of common land, which was exploited for grazing, fuel (wood and peat) and building materials (stone and turf). The fraction of the land area that was cultivated fluctuated according to population and climatic changes, but, at least from the seventeenth century onwards, an increasing proportion of the uncultivated land came into cultivation.

The Basis of Land Tenure

From around 1150, the rulers of Scotland introduced a feudal system of land tenure to the lowlands of Scotland, although more distinctly Celtic or Nordic arrangements did survive much longer in the West and North. In the East of Scotland, as defined here, the changes were complete by 1250, after the military subjugation of the last Celtic rulers of Moray. Although formally styled King or Queen of Scots, the medieval rulers of Scotland considered themselves to be outright owners of all of its land. The concept of feudal tenure was imposed on England by the invading Normans (i.e. from

Denmark via Normandy and Brittany); it diffused into Scotland with the migration of Normans, invited north by Scottish kings who were intent on the Europeanisation of their predominantly Celtic country (introduction of the Roman Catholic Church; fostering of trade and urban development; centralisation of authority). Under the evolving feudal system, parcels of land were granted indefinitely to favoured individuals and their descendants, and to various institutions of the church. These grants were in return for a commitment to provide military support (men, arms and supplies) as required, but also hospitality when the court or its officers were travelling. Those who held land directly from the crown in this way (the barons) were responsible for local law and order, holding the power of life and death over the inhabitants of their barony. The land could be repossessed by the king if the baron failed to perform; nevertheless, with the passage of time, barons came to consider themselves as land owners, and a legal system developed to keep track of the buying and selling of land.

Baronies varied enormously in size from a few hundred to many thousand hectares, and groups of baronies could be organised into regalities held by major magnates. Normally, the baron was not actively involved in agricultural production; he distributed the land of the barony to tenants (tackholders or tacksmen), in a range of legal arrangements, which, by the end of the seventeenth century, normally involved a written legal contract, covering less than 20 years, which laid out the details of the rent to be paid (in the form of agricultural produce, principally grain) and the services to be rendered (harvest labour, peat cutting, haulage, acting as messengers, maintaining the barony mill). Later, tacks included options for payment in cash. The tacksmen could manage the

land himself or sublet to others, but the considerable amount of manual labour required for the existing agricultural system was supplied by numerous landless cottars. This form of land distribution led to separate nuclei of settlement occupied by small groups of families (fermtouns), rather than larger villages, except in the Merse and East Lothian. Under the feudal system, land was a source of subsistence and labour for the baron and, ultimately, the king; it was not, primarily, a source of cash income. There was no tradition of small-scale landownership; even the smaller landholdings which were created out of the great religious baronies at the Reformation were largely re-absorbed by larger estates in subsequent centuries.

The Improvements

Much has been made of the very primitive state of agriculture in Scotland before the Improvements, and the role of the Union of Scotland and England (1707) in promoting agricultural progress. Recent historical research has shown that this is a simplification; the records of grain exports to continental Europe through east coast ports in the seventeenth century show that parts of the country were already well above the subsistence level, and implementing new knowledge from the Dutch as well as from England. A run of very poor harvests immediately before 1707 has served to distort the record.

Nevertheless, starting around 1700 in the South of Scotland, and moving in an irregular wave through the lowlands, an "agricultural revolution" did reach most parts of the North-East lowlands by around 1820. The rate of change accelerated after 1750. This revolution was facilitated by major changes in the legal system, in social organisation, and in national politics, which tended to alter the world view of landowners; they changed from being the

leader of the baronial community (including the role of dispenser of justice) to the controller of natural and human resources which could be exploited for cash. The Improvements involved numerous changes, including:

- direct involvement of the owner or his factor in farming and farm management
- reduction in the number of tenants
- consolidation and rationalisation of holdings, and the creation of walls, fences and hedges to control livestock
- division and enclosure of common land
- technical advances in crop production (e.g. liming; introduction of new rotations, featuring new species such as turnips, pasture legumes and sown grasses; improved varieties and seed quality; the change from grass-fed ox to grain-fed horse power; improved implements; some drainage)
- technical advances in livestock production, including better integration of crop and livestock production (e.g. improved breeding; higher productivity; introduction of forage crops, and conservation of grass as hay, permitting overwintering of greater numbers of livestock; more, and higher-quality manure)

Subsequent major improvements in the nineteenth century involved under-drainage, the use of imported mineral fertilisers such as guano, and progressive mechanisation. Another important development in the seventeenth and eighteenth centuries was the reclamation of fertile coastal areas and carselands by extensive drainage systems and the removal of vast quantities of lowland peat.

Modern Times

The Improvements laid the foundation for the major inter-related features of Scottish agriculture in modern times: large units (by Northern European standards), low rural population, intensive production systems (but with functional connections between crop and livestock production), and an industry tuned to national and world trends rather than local or subsistence priorities.

The consolidation and rationalisation of the land within large estates led to the rise of a class of major tenants, farming areas of the scale of 40 hectares (100 acres), occasionally more, with a substantial stone-built house and steading. These tenants paid cash rents and marketed their products independently. They had security of tenure and could normally pass the tenancy to the next generation. During the twentieth century, consolidation continued, and a high proportion of individual farms became owner-occupied: at the 1998 agricultural census, the mean area of crops and grass per holding in the study area was 68 ha (170 acres) (see Tables 1.3 and 1.4).

In the course of the eighteenth century Improvements, the remaining tacksmen and cottars were relegated to the status of farm servants (engaged for periods of months, and housed on the farm) or day labourers. The fermtouns were largely destroyed in the process of consolidation, and disappeared entirely from the landscape; in some areas, even their names have been forgotten. They were replaced by sufficient cottages to house the labourers required by the farm. This pattern was not uniform throughout the area. For example, in the North-East, it was common for improving landlords to create small holdings at the boundary of the intensively-managed land; tenants were offered generous initial terms to induce them to bring the land into cultivation. In the nineteenth century, there

were no government policies for land redistribution, as in Denmark and Ireland, except in the crofting areas of the western seaboard, which are outside the scope of this handbook. However, the government did purchase and distribute a substantial area of land in the form of smallholdings (around 10 ha each) to returning servicemen after 1918 and 1945. Unlike Norway, the clearing and reclamation of land did not confer “squatter’s rights” on the occupant.

As a result of the Improvements and related changes, large numbers of displaced tacksmen and landless cottars began to leave the land early in the eighteenth century, and this flow increased sharply towards the end of the century. Thus “clearances” did occur in the lowlands, before the more spectacular events in some highland areas, but gradually and less

violently; they also occurred at a time when non-agricultural employment in lowland areas was expanding at the beginning of the “industrial revolution” (notably handloom weaving, succeeded by mechanised textile industries, mining and iron production). The early agricultural improvements gave higher yields and returns to the tenant and owner, although they still relied heavily on human labour, particularly at harvest. However, as mechanisation developed, the need for labour declined. The net result was that Scotland, one of the least urbanised countries in 1700, had the second lowest rural population in Europe (behind England) by 1850, and nearly the fastest recorded rise in urban population in the nineteenth century (Table 1.2). No other country in Europe experienced such sharp demographic changes in the eighteenth century. For reference, the proportion of

Table 1.2 Proportion (%) of the population of European countries living in towns with more than 10,000 inhabitants.

	1600	1650	1700	1750	1800	1850
Scotland	3.0	3.5	5.3	9.2	17.3	32.0
Scandinavia	1.4	2.4	4.0	4.6	4.6	5.8
England & Wales	5.8	8.8	13.3	16.7	20.3	40.8
Ireland	0	0.9	3.4	5.0	7.0	10.2
Netherlands	24.3	31.7	33.6	30.5	28.8	29.5
Belgium	18.8	20.8	23.9	19.6	18.9	20.5
Germany	4.1	4.4	4.8	5.6	5.5	10.8
France	5.9	7.2	9.2	9.1	8.8	14.5
Switzerland	2.5	2.2	3.3	4.6	3.7	7.7
N Italy	16.6	14.3	13.6	14.2	14.3	
C Italy	12.5	14.2	14.3	14.5	13.6	20.3
S Italy	14.9	13.5	12.2	13.8	15.3	
Spain	11.4	9.5	9.0	8.6	11.1	17.3
Portugal	14.1	16.6	11.5	9.1	8.7	13.2
Austria-Bohemia	2.1	2.4	3.9	5.2	5.2	6.7
Poland	0.4	0.7	0.5	1.0	2.5	9.3

Source: de Vries, J. (1984). *European Urbanisation, 1500-1850*. Harvard University Press.

people in Scotland living in towns larger than 10,000 inhabitants was 65.5% at the 1991 census.

Once these changes had started, there was no going back, and the future of Scottish agriculture could lie only in intensification. However, the topography of the East of Scotland, with the arable areas constituting a coastal strip, bounded inland by relatively high hills, did not lend itself to "prairie" cropping. There are also considerable areas of "difficult soils", owing to texture or water relations, where the inclusion of a grass crop in the rotation is necessary to maintain the soil structure; and there are problems of slope and stoniness. This has ensured that, in contrast to England and continental Europe, mixed farming, integrated with the livestock enterprises of adjacent upland areas, has persisted up to today in most parts of the study area.

Finally, the abrupt and fairly complete change from subsistence to commercial cropping in the eighteenth century, has meant that Scottish farmers have been in competition with those in other countries ever since. They benefitted from the increase in demand for food from the expanding cities and from the general boom conditions during the Napoleonic Wars, and suffered from the subsequent collapse. Over the last two centuries, with the repeal of the Corn Laws (1846) and increasing supplies of cheap food from the British Empire, there has been more depression than boom, except in the war years of the twentieth century. Although, in general, the years under the Common Agricultural Policy of the EC/EU have been ones of prosperity and development, the late 'nineties have seen a sharp fall in farm incomes, initiated by the collapse in livestock sectors and problems associated

with currency exchange rates (see Table 1.5).

One important feature of modern times has been the scientific leadership generated in Scotland. The first chair in agriculture in the English-speaking world was established in Edinburgh over 200 years ago and, particularly in the twentieth century, the organisations listed in Appendix 1 have contributed strongly to advances in agriculture, food, the environment and biotechnology, not only for Scotland and the UK, but also on the international stage.

Suggested reading for further historic background:

Devine T.M. (1999). *The Transformation of Rural Scotland*. Edinburgh: John Donald Publishers;

Devine T.M. (1999). *The Scottish Nation 1700-2000*. London: Allen Lane;

Fenton A. (1976). *Scottish Country Life*. Edinburgh: John Donald Publishers;

Sanderson M.H.B (1982). *Scottish Rural Society in the 16th Century*. Edinburgh: John Donald Publishers;

Whittington G.W. & Whyte I. (1983). *An Historical Geography of Scotland*. London: Academic Press;

Whyte I. (1979). *Agriculture and Society in Seventeenth Century Scotland*. Edinburgh: John Donald Publishers;

Wightman A. (1996). *Who Owns Scotland*. Edinburgh: Canongate.

Many issues in relation to land tenure and rural populations can be explored by comparing the experiences of the characters in *Growth of the Soil* (Knut Hamsun) with those in *Sunset Song* (Lewis Grassie Gibbon) and *Butcher's Broom* (Neil Gunn).

The Pattern of Farming Today

Tables 1.3 and 1.4 give a snapshot of farming in the East of Scotland, using data from the 1998 Agricultural Census (AEFD, 1999a) for: Scottish Borders, Lothian, East Central, Fife, Tayside and North-East Scotland. Detailed analyses of cropping and crop yields are presented in Chapter 4. Unlike the areas used for the calculations in chapters 2 and 4, these census data also

incorporate a substantial proportion of upland farming, with a greater concentration on livestock production and forestry.

The census data confirm:

- the relatively large mean arable area per holding;
- the low (less than 4% of the agricultural area) but expanding area of woodland;

Table 1.3 Characteristics of farms in the East of Scotland, 1998 (AEFD, 1999a).
All data, except glasshouses, are expressed per holding.

Area	Arable area ^a , ha	Total area ^b , ha	Woodland ^c , ha	Glass-houses ^d , m ²	Total workforce ^b
Scottish Borders	94.7	110.6	15.6	7,386	3.1
Lothians	81.7	81.9	10.9	56,502	3.4
East Central	41.3	57.1	13.7	21,127	2.6
Fife	83.0	82.3	8.8	27,270	3.2
Tayside	72.0	78.0	18.6	92,766	2.8
North-East	58.2	60.6	11.9	41,466	2.3

a: mean over farms with arable;

c: mean over farms with woodland;

b: mean over all farms, excluding rough grazing;

d: total for area.

Table 1.4 Characteristics of livestock production in the East of Scotland, 1998 (AEFD, 1999a). All data, except total cattle and sheep, are expressed per holding

Area	Dairy cows ^a	Beef cows ^b	Total cattle ^c	Sheep ^d	Total sheep ^c	Pigs ^e	Poultry ^f
Scottish Borders	94.5	76.7	153,744	1476	1.482m	456	2,908
Lothians	73.2	63.9	54,385	891	0.273m	1,548	16,508
East Central	74.2	43.6	66,379	963	0.428m	136	10,040
Fife	81.3	57.9	60,765	532	0.116m	873	23,081
Tayside	82.5	54.1	129,824	937	0.816m	1,087	12,514
North East	91.3	54.1	387,422	410	0.751m	1,131	3,353

a: mean over dairy farms;

d: mean over sheep-rearing farms;

b: mean over beef-rearing farms;

e: mean over pig-rearing farms;

c: total number for area;

f: mean over poultry enterprises

- the fairly limited area of intensive horticulture, concentrated near the cities of Edinburgh, Dundee and Aberdeen - as are intensive dairy, pig and poultry production;
- the small workforce (60,148 for the whole of Scotland, equivalent to 29.3 ha of crops and grass per worker), indicating a high degree of intensification and mechanisation (and efficiency in terms of output per unit of labour);
- the integration of crop and livestock agriculture (much of the cereal produced goes to support intensive dairy, beef, pig and poultry production; and lowland grassland supports the dairy industry, and the fattening and overwintering of cattle and sheep);
- the large size of the units of livestock production (on a European scale).

In spite of the high yield potential of arable cropping in the East of Scotland, the traded

agricultural products of the area are predominantly livestock and industrial products. This reality is reflected, for example, in the concentration of resources for education and research in Scotland on animal and veterinary science (see Appendix 1).

The contribution of agriculture to the Scottish economy is summarised in Table 1.5. The main features of the analysis are:

- the declining income from agriculture (Income in 1998 = 31% of that in 1995), owing to a range of factors including the depression of prices caused by the strength of the pound and the sharp decline in the livestock sector (BSE and overproduction in the sheep/pig sectors)
- the predominance of livestock products (63.4% of output in 1994; 60.1% in 1998)
- the very small direct contribution that agriculture (employing 60,000) makes to the Scottish economy (GDP = ca £60bn, employing 1.3m)

Table 1.5 The Financial Status of Scottish Agriculture by Sector (£m)

Output	1994	1995	1996	1997	1998
Cereals	320	423	432	340	296
Other Crops	184	284	179	133	178
Horticulture	75	84	92	87	95
Finished Livestock	942	1036	1033	968	858
Store Livestock	54	53	48	47	36
Livestock Products	327	331	341	307	274
Gross Output	2,087	2,409	2,318	2,111	1,943
Gross Input ^a	1,054	1,091	1,177	1,124	1,095
Gross Value Added ^b	1,033	1,318	1,142	987	848
Total Income from Farming ^c	493	743	555	365	231

Source: Economic Report on Scottish Agriculture. (AEFD, 1999b)

a: seeds, fertilisers, feed, machinery etc.;

b: Gross output - gross input;

c: Gross value added - fixed capital costs, subsidies, hired labour, interest and rent.

2. CLIMATE



August cereal harvest under optimal conditions, near North Berwick, East Lothian

The climate of the East of Scotland is temperate without extremes of temperature or rainfall but, although meteorological catastrophes are rare, the success of agriculture is dominated by weather. Effects can be direct, such as the destructive influence of freezing temperatures, or indirect, through the vulnerability of wet land to compaction by heavy machinery. It is common for crop yield to be influenced by interactions between soil type and water relations, or temperature.

The weather in Scotland is dominated by the particular air mass passing over, since it lies close to the track of depressions from the North Atlantic. The prevailing winds are predominantly from the south west, bringing humid air, which deposits precipitation when forced to rise over the Western and Central Highlands, and the Southern Uplands. By the time that such airflows reach the East of Scotland, much of the moisture content has been lost (rain

shadow effect). A “blocking” anticyclone over Scandinavia or the Bay of Biscay can push the depressions further west or north, resulting in generally drier, more continental weather. In winter, climatic differences tend to run east-west whereas in summer they run north-south. East-west differences also arise from the proximity to the coast, on the one hand, and mountains on the other.

Francis (1981) classified the agricultural areas of Scotland using mean annual rainfall, as soil water rather than growing season length (based on temperature) is the dominant limiting factor for cropping in Scotland. He compiled tables of many meteorological and agriculturally-relevant attributes for each area (Table 2.1). Although his calculations were based on data from the period 1941-1970, current figures are broadly similar. However, variation from season to season is usually more important than long term averages: when decisions are being made about capital investment in plant and machinery, a balance must be struck between the needs of the “average” season and the risks associated with more extreme events; in the shorter term, decisions on the rate and timing of inputs must be made in ignorance of the actual conditions to be encountered by the crops.

For land capability purposes (see Chapter 3), Scotland has been mapped using the median value of the highest potential soil water deficit and the lower quartile value of accumulated day-degrees above 0°C for the first six months of the year (Bibby et al., 1991; note that physiologists prefer to use degree days). The former is really an index of how wet rather than how dry the site is whereas the latter determines which crops can be fitted into the growing season

Table 2.1 Selected climatic data for regions in the East of Scotland

	Borders	Lothian	Fife	Angus & Perthshire	NE Scotland	Inverness & E Ross
Growing season (d)	215	225	225	220	210	215
Mean winter temperature (°C)	5.1	4.3	5.0	4.5	3.7	4.7
Mean summer temperature (°C)	12.0	11.2	12.0	11.7	10.7	11.4
Last spring frost ^a	Apr III	Apr II	Apr II	Apr II	May I	Apr III
Annual rainfall (mm)	813	675	825	912	888	803
Mean PET ^b (mm)	465	500	473	440	415	443
Access period ^c (d)	203	240	205	182	170	198
First soil moisture deficit	Mar I	Mar I	Mar I	Mar I	Mar II	Mar I
Return to field capacity	Oct II	Nov II	Oct II	Oct II	Oct II	Oct III
Highest summer SMD ^d (mm)	83	100	83	72	68	78
Excess winter rainfall (mm) ^e	310	195	320	395	368	303

Source: Francis (1981);

a I = first 10 days of the month etc.;

b PET=potential evapotranspiration;

c access for farm machinery;

d SMD=soil moisture deficit;

e rainfall which must be removed by drainage (i.e. allowing for soil water recharge and evaporation)

(based on temperature). Winter wheat, barley, oilseed rape and potatoes are generally well-adapted to the climate of the East of Scotland, with pasture grasses thriving in the wetter parts. Adapted species of coniferous and broadleaf trees grow well, with high yield classes in favourable locations.

Temperature

Analysis of long term records shows that air temperatures below -15°C or above 30°C are extremely rare. The mean annual air temperature, as measured in standard meteorological screens, is about 8.5°C for the whole area, with lower temperatures inland and towards the altitudinal limit of cultivation. The range from the coldest (January) to the warmest (July) month is typically also 8.5°C, which is slightly greater than the mean diurnal temperature range of 7°C. As the air temperature increases on average by only 0.33°C per

day during February, March and April, late frosts and reversions to winter weather are common in early spring. In Table 2.1 the mean date of the last spring frost is given in months and dekads (ten day periods). The inter-quartile range is about four weeks, showing the considerable variation among growing seasons.

Temperatures are too low to allow successful commercial growing of maize, sunflower or soya, although in recent years forage maize has been grown in the slightly warmer South-West of Scotland. For well-adapted species (wheat, barley, potatoes, grassland), temperatures are generally sub-optimal for growth rate (i.e. <20°C) but conducive to slow development and prolonged canopy duration. Since the growing season of winter cereals can span virtually the entire calendar year, they can maximise the interception of solar radiation. However, reliance on winter cereals is not without difficulties. For example, a typical rotational transition from

ware potatoes to winter wheat can pose problems if the potato harvest is late, as is often the case; and there is a limited choice of crops to precede winter oilseed rape, which is normally drilled in August. (The implications of winter cereals for disease epidemiology are discussed in Chapter 5).

The minimum temperature for growth of many temperate crop species is around 0°C but growth rates are low below 6°C. The growing season for grassland species is, therefore, commonly defined as the number of days when the mean daily soil temperature at a depth of 0.30 m is above 6°C, giving typical values around 210 days, rising to 225 days in coastal parts of the Lothians (Table 2.1). Even at 6°C, mineralisation of nitrogen in the soil is inhibited, such that the onset of rapid growth is delayed in crops not supplied with fertiliser nitrogen. Mean air temperature declines by 0.6 to 1.0°C for each 100 m increase in altitude, and, because of the low rate of increase in temperature with time in spring, the potential growing season falls off rapidly with altitude.

Agriculturally, the temperature of the top 5 cm of soil is more important than the air temperature, because, for example, the

apical meristems of cereal and grass plants remain below the soil surface during vegetative growth; nevertheless, air and soil-surface temperatures are normally well-correlated (Hay, 1976, 1977; Hay et al., 1978). The temperature of soils which are intrinsically wet (owing to texture, structure or drainage), tends to lag behind air temperature and the onset of rapid growth can differ by more than a week between neighbouring but contrasting soils. In the case of grassland, this can be important for the turning out of livestock in the spring.

Raised beach soils in the Lothians were traditionally used to grow early vegetables because their sandy texture allowed them to warm up quickly in spring, but they were also vulnerable to frost. Although cereal and grassland crops are resistant to the levels of freezing stress experienced in the East of Scotland, frosts as late as 20 May (Figure 2.1) can delay the canopy development of potato and sensitive vegetable crops, with consequent yield losses.

Water

Long term average precipitation is fairly evenly distributed throughout the year,

Figure 2.1 Date of last spring frost (grass minimum temperature) at three meteorological stations in the East of Scotland, 1961 - 1999.

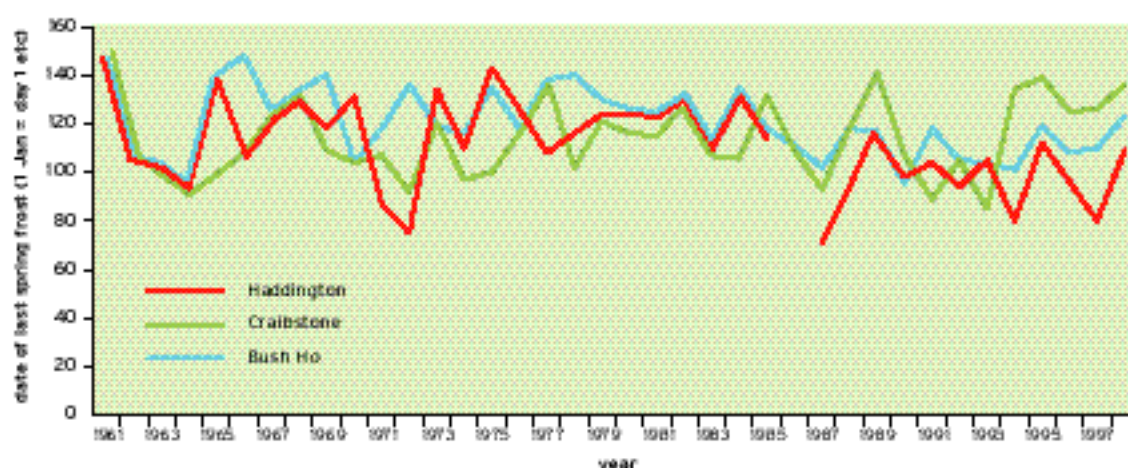
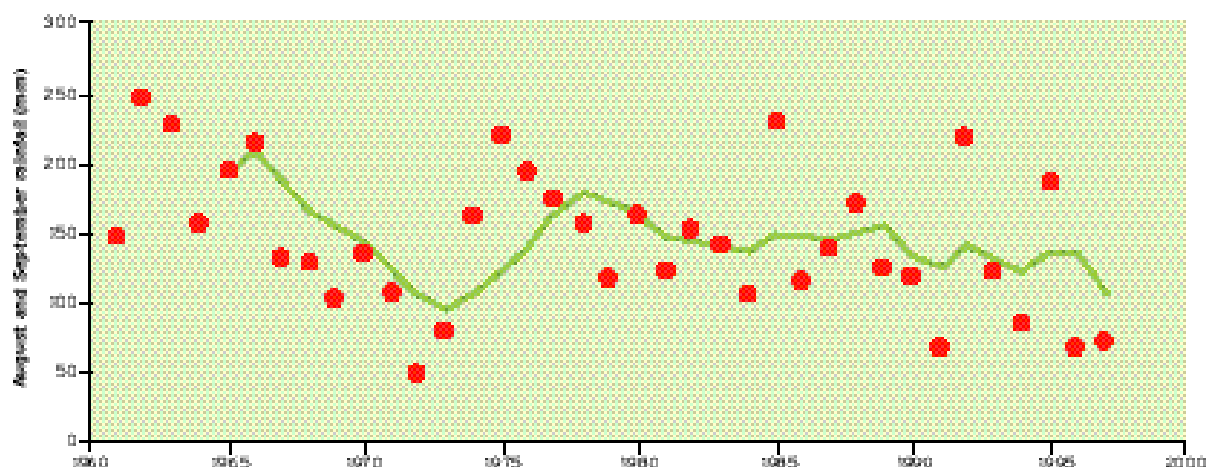


Figure 2.2 Mean August and September rainfall at three meteorological stations in the East of Scotland, 1961 - 1999. The curve is fitted to five-year running means.



although there is considerable variability from year to year (Table 2.1). There is a tendency towards drier weather in February to April, and the harvest months of August and September can be very wet (Figure 2.2). The driest areas are those on the South-East and Moray Firth coasts where the average annual rainfall is less than 600 mm. Annual precipitation increases to the west because of an increase in altitude and proximity to the wetter west coast. As a rule of thumb, arable agriculture is not viable when annual rainfall exceeds 1000 mm.

In Scotland, rainfall per se is not usually the limitation to agriculture but rather soil water status, which depends on the balance between precipitation on the one hand and losses from evapotranspiration and drainage on the other. Temperature sets the potential length of the growing season for all crops, as outlined above; however, with mechanised agriculture, the actual growing season is effectively restricted to the period when there is a soil water deficit (Table 2.1), so that the soil is sufficiently strong to support the weight of cultivating, planting and harvesting machinery without suffering

damage. There is very considerable inter-annual variation in soil water content, superimposed on the annual cycle. For example, Francis (1981) estimated that, over the years 1957-75, the first soil moisture deficit in spring occurred outside the period 21 February to 20 March in half of the growing seasons; the corresponding range for autumn return to field capacity was 20 October to 30 November (Hay, 1993). The difference between the actual and potential growing season can, of course, be reduced by the use of winter-sown or perennial crops, thus reducing the need for traffic in spring.

Over the twenty year period up to 1999, the cumulative rainfall from April to July (the main period of crop growth) ranged from 50 to 150% of the mean, such that crop establishment could be hindered as much by too little as by too much soil water. August and September rainfall (Figure 2.2), which is important for the harvest of cereals, bulking of main crop potatoes and (October) drilling of winter cereals, is also rather variable. Winter rain, which influences the leaching of nutrients over the winter period and the degree of

waterlogging of poorly-drained soils, can exceed 600 mm in the western parts of the area in wet years. Even in the arable areas, drains should be designed to remove 400 mm of water over the winter period (Table 2.1). As many soils are naturally imperfectly-drained, artificial under-drainage is essential to enable machinery to get on the land as soon as possible.

Snowfall is generally light and does not have a major influence on agriculture although damage to buildings has been caused by heavy falls of wet snow, and flooding can be caused by late or very rapid snow-melt in the hills.

Potential transpiration in the first six months of the hydrological year (April to September averages 400 mm (370-425 mm), with lower values in the north and at the upper limits of agriculture. Year to year variation, which depends on solar radiation, is not large compared with variation in rainfall. Actual transpiration is often close to the potential but falls below it as the soil water deficit increases. As a consequence of this pattern of hydrology, soil water deficits are typically small, and return to field capacity is not uncommon within the growing season of arable crops. In the driest areas, irrigation is needed virtually every year for potatoes, for example, with up to 120 mm of water applied on average to keep the soil water deficit below 40 mm. However, over much of the remaining area a deficit of 50 mm (about half the profile-available water) would be exceeded in only half of the years. The significance of the soil water deficit for agriculture depends on the available water capacity of the soil, and, therefore, on soil type. For example, irrigation is sometimes carried out in areas where there are low deficits but the soil is stony, resulting in a low available water capacity.

Rain during the early stages of grainfilling in wheat can induce premature production of alpha amylase, thus reducing the Hagberg Falling Number (HFN) of the grain sample. As a consequence, Scottish wheat rarely achieves a HFN which is sufficient for breadmaking. The harvest period for grain crops tends to be humid (Figure 2.2) and, since the grain reaches an equilibrium with the relative humidity of the atmosphere, it is commonly harvested at moisture contents above the critical level for safe storage. As relative humidity is inversely related to temperature, the proportion of the day during which grain drying occurs in the ear decreases progressively in late summer and autumn, and artificial drying is commonly required. Wet weather at harvest can cause significant loss of yield owing to disease and mechanical problems, and quality, for example of malting barley, owing to sprouting in the ear. It also results in soil damage, and delay in the drilling of a following crop.

Although significant areas of agricultural land are on flood plains, flooding is rarely a major problem for agriculture, and farming systems have adapted in those areas where it is a regular hazard.

Solar Radiation

Contrary to the general perception, the receipts of solar radiation in the East of Scotland during the period April to September are similar to those in the south of the UK. About 60% of the solar radiation is received as diffuse radiation, the proportion increasing slightly with altitude. However, since the daily receipt is spread over a longer photoperiod, soil and air temperatures are significantly lower in Scotland (Hay, 1993). Thus cropping in the East of Scotland is carried out under "cool long days" - at least cooler and longer than

at lower latitudes. Since the rate of crop development and the duration of the crop are determined by temperature, but yield is determined by the total amount of intercepted radiation (Monteith, 1981; Hay & Walker, 1989), these conditions are conducive to high yields of adapted species (see the comparison of cereal yields in England and Scotland in Chapter 3).

Wind

Scotland is generally exposed to high winds, and the East of Scotland, although partly protected from the prevailing south westerlies, is very open to the North and East, except where there is significant shelter from the topography. The strongest winds are, however, in winter when crops are least vulnerable. Shelterbelts are a common feature but were planted originally for reasons varying from protection of stock to enhancement of the landscape, rather than to increase crop growth. Indeed, the benefits and disadvantages of shelter for arable agriculture are still debated. For cereals, prevention of grain loss through ear loss or grain shedding; and for both cereals and oilseed rape, resistance to lodging; are very important aspects of varietal selection for exposed areas.

Local Climates

Towards the margins of arable agriculture, relatively small differences in local climate make a significant difference to the viability of agricultural enterprises. The importance of aspect is not as great as it would be if the diffuse component of solar radiation were less. However, raspberries are grown on sheltered south-facing slopes such as those of Strathmore near Blairgowrie. There are local effects of rain shadows particularly in the lee of the Grampian Mountains and a narrow coastal zone is typified by significantly higher solar radiation and lower rainfall than locations even only 10 km further from the sea.

Nevertheless, easterly winds can bring warm air that is chilled below its dew point by passage over the North Sea, resulting in a coastal blanket of mist (haar) up to 15 km inland. Although it frequently disappears by mid-day, it can persist for days at a time, with a consequent delay in the warming up of soils in spring, and reduction in receipts of solar radiation. Predominantly a spring phenomenon, haar can also slow the drying of grain at harvest.

3. GEOLOGY, SOILS AND LAND CAPABILITY



Undulating Class 3 arable land, formed on till and fluvioglacial material of ORS (Devonian) lavas and sediments, Lomond Hills near Kinross

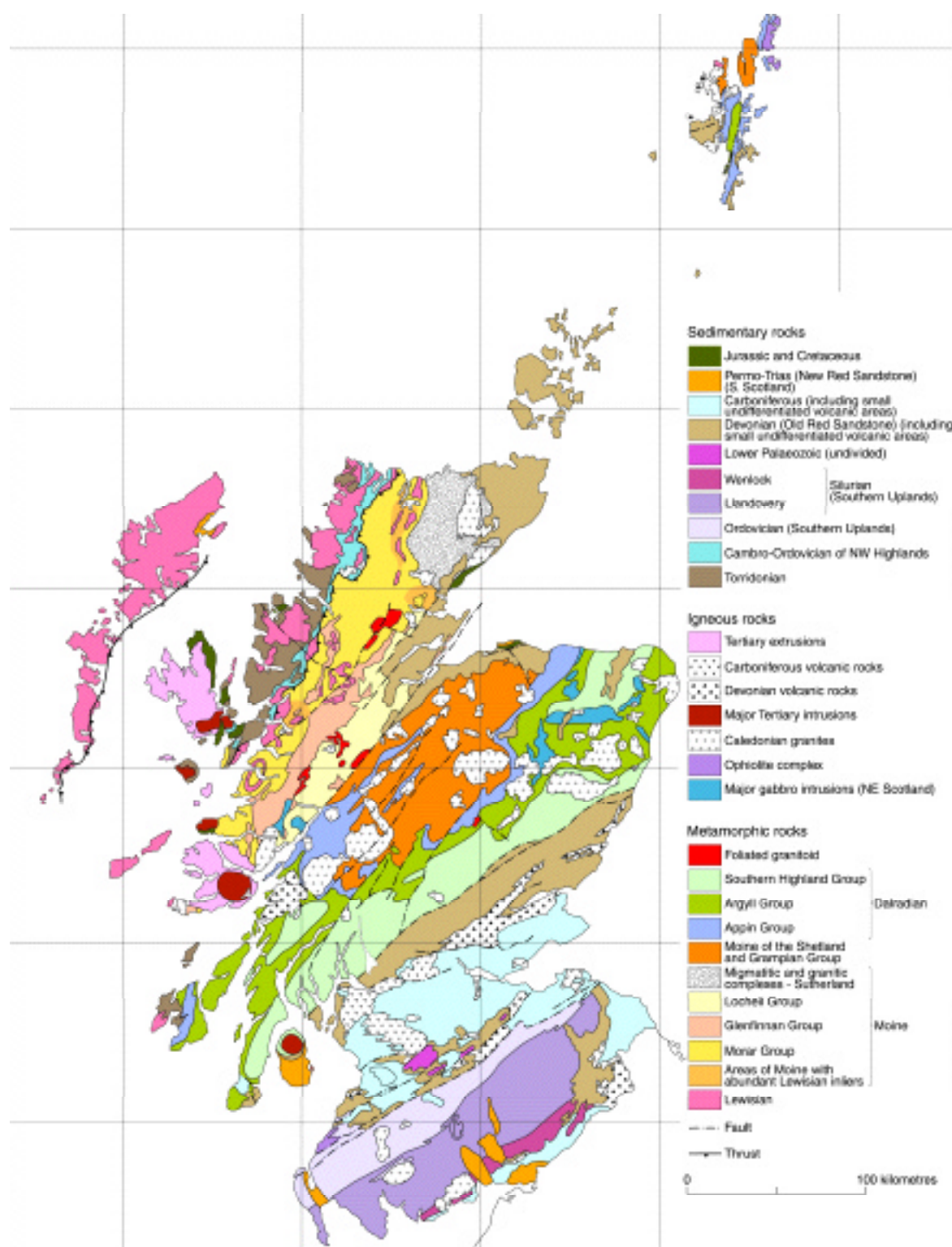
Geology

For the purpose of this handbook, the geology of the East of Scotland can be simplified into three blocks: the Midland Valley, clearly demarcated from the Eastern Highlands by the Highland Boundary Fault and, from the Southern Uplands, by the Southern Upland Fault (Figure 3.1).

- The Southern Uplands, rolling hills rising to altitudes around 600m, are relatively simple geologically: predominantly shales and greywackes (metamorphosed abyssal fine sandy sediments) of the Ordovician/Silurian (O/S) period, with some sedimentary rocks of the Devonian and Carboniferous periods. The O/S rocks contribute little to the arable soils in Table 3.1.
- The Midland Valley, is dominated by sandstones, calciferous sandstones, shales and limestones of the Carboniferous period (but without the thick Mountain Limestone strata of the North of England). Between these rocks and the Highland Boundary Fault are sandstones of the Devonian period (the "Old Red Sandstones" - ORS). There are also very extensive intrusive and extrusive areas of igneous rocks, predominantly basalt, notably in North Fife, and the Lothians. Under glaciation and weathering, these rocks, and the Carboniferous rocks in particular, yielded soil-forming materials of high base status and fine texture. The ORS tended to give coarser, typically dark red, materials of lower base status.
- The Eastern Highlands, more rugged terrain rising to 1000m, are composed predominantly of ancient Dalradian (south) and Moinian (north) metamorphic rocks (various schists with gneisses, slates etc.: part of the land mass which included much of N. Canada, Greenland, Norway & Sweden), with substantial areas of intrusive and extrusive igneous rocks (granite and gabbro). There is an important northern fringe of ORS, which is internationally-famous as a source of fossils of Devonian fish. Under glaciation and weathering, the Dalradian and Moinian rocks yielded a great variety of predominantly coarse and base-poor soil materials, but, in mixture with igneous rocks, could give base-rich materials.

The last glaciation of Scotland was complete and extensive, leaving deep layers

Figure. 3.1 Simplified geological map of Scotland



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of till/drift over the lowlands of the East of Scotland. The origin of the till depends upon the direction of movement of the ice sheets and glaciers. In the South of Scotland, the direction of movement was predominantly west to east, with the result that much of the till covering the Lothians, the Merse and the southern half of Fife is of Carboniferous origin. Further north, the direction was more north to south, such that the till covering Tayside (Perth and Angus) is mainly of ORS origin, as shown by the distinct red soils of the area. There are also significant areas where the till is composed of igneous material of ORS age (e.g. N. Fife). The lowlands of Banff and Aberdeenshire are covered with till from Dalradian and igneous rocks carried eastwards. There are pronounced local differences; for example, the four extensive soil associations of arable Aberdeenshire are formed on tills of contrasting chemistry (Foudland: Dalradian schist; Inch: mixed till of gabbro and schist; Tarves: mixed till of acid and basic igneous rocks; Countesswells: granite till; Table 3.1), each relating to the “upstream” geology. Finally, the direction of flow in the Moray Firth area was south west to north east, such that the till is made up of Moinian schist and granite.

Two other aspects of the glaciation of the East of Scotland are important for soil formation. First, the mass of ice was particularly great on the Northern and Eastern Highlands, with the result that fluvio-glacial processes, which washed out the finer components of the till, were very active and prolonged during the period of deglaciation. Thus there are more extensive areas of fluvio-glacial sands and sandy loams in the northern half of the study area, and particularly in the Laich of Moray (Corby/Boyndie Soil Association; Table 3.1), than in the southern half. Secondly, the weight of ice pressing on lodgement till, has tended to compress the

material, with the result that most soils, even those with relatively coarse textures, have subsoils with lower hydraulic conductivities than would be predicted from their texture.

Soils

The soil types which have formed from this variety of parent materials over 10,000 years depend upon the interactions of several factors:

- the texture of the parent material
- its base status
- its hydraulic conductivity
- topography
- annual precipitation
- vegetation (mull or mor humus)

which determine the degree and type of leaching and/or waterlogging of the soil profile. These processes have produced four major arable soil types, to which must be added the more recent alluvial soils (Table 3.1; Figure 3.2):

Brown Forest Soil

Key factors lowering the rate of leaching, and preventing podzolisation or waterlogging: high initial base status, particularly with igneous components; sandy loam to loam texture; free but not excessive drainage; natural vegetation broadleaf woodland with mull humus. More prevalent in the southern half of the study area. (Carpow/Panbridge; Darleith; Darvel; Hobkirk; Inch; Sourhope; Tarves)

Brown Forest Soil with Gleying

Key factors: high initial base status (particularly Carboniferous till); medium to

fine texture, possibly with compressed (indurated) subsoil, leading to imperfect drainage; low rainfall preventing gleying of upper horizons; natural vegetation broadleaf woodland with mull humus. Major soils of the Lothians and Fife: potentially the most fertile soils, under low annual rainfall, owing to high base status and high water-holding capacity). (Balrownie; Kilmarnock; Mountboy; Winton; Whitesome)

Humus Iron Podzol

Key factors: low initial base status (fluvioglacial deposits or coarse

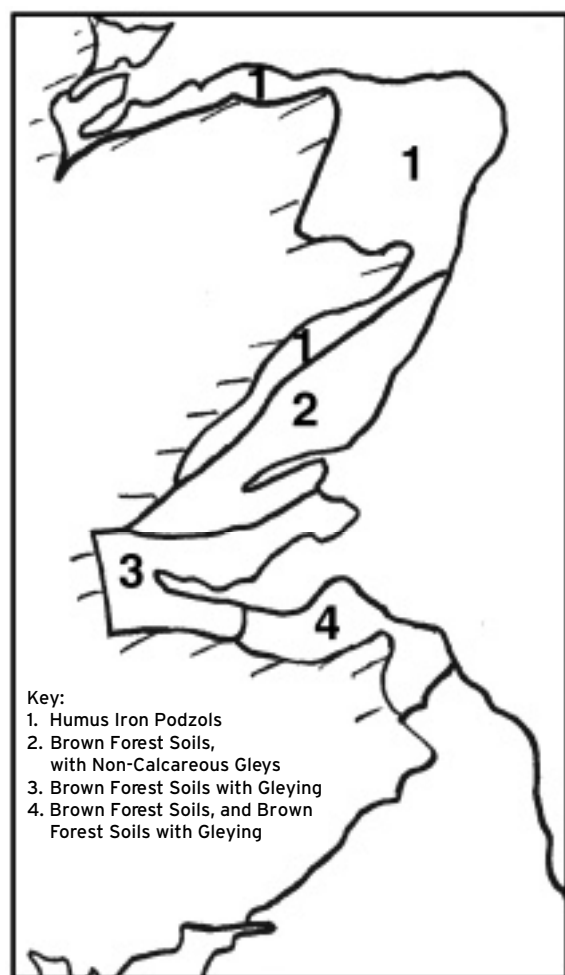
granite/schist till); sandy loam texture giving very free drainage; high rainfall not necessary; natural vegetation heath or coniferous woodland. Major soils of the North East but now effectively indistinguishable from Brown Forest Soils owing to the mixing of horizons by ploughing. (Corby/Boyndie; Countesswells; Forfar; Foudland).

Non-Calcareous Gleys

Soils which were waterlogged until around 1,000 years ago or later, now freely-draining, but natural soil-forming processes have been arrested by cultivation. (Stirling).

A set of representative soil profiles is presented in Appendix 2.

Figure 3.2 Schematic map of the major soil types in the East of Scotland



(adapted from Coppock, 1976)

Land Capability

In the UK, information on climate, soil, topography and other physical properties are combined to give the Land Capability (formerly the land-use capability) of an Area (Bibby et al., 1991). Only the first four of the seven classes are suited to arable agriculture:

- **Class 1:** Land capable of producing a very wide range of crops. Cropping is highly flexible and includes the more exacting crops such as winter harvested vegetables (cauliflowers, brussels sprouts, leeks). The level of yield is consistently high. Soils are usually well-drained deep loams, sandy loams, silty loams, or their related humic variants, with good reserves of moisture. Sites are level or gently sloping and the climate is favourable. There are no or very minor physical limitations affecting agricultural use.
- **Class 2:** Land capable of producing a wide range of crops. Cropping is very flexible and a wide range of crops can be grown though some root and winter

Table 3.1 Major Arable Soils of the East of Scotland. Map units > 200km²; from Brown & Shipley, 1982; Walker et al, 1982

Soil Association	Map Unit	Extent, km ²	Principal Areas	Soil Parent Material	Texture	Prelominant Soil Type
Alluvium	1	674 (E) 437 (SE)	River valleys, flood plains in North East	Freshwater alluvial deposits	Loam/sandy loam over gravel	Alluvial soil
*Balrownie	41	948 (E) 271 (SE)	Perth & Angus	ORS Sandstone till	Loam over sandy loam/ sandy clay loam	Brown forest soil with gleying
*Carpow/Panbridge	89	129 (E) 86 (SE)	Fife & Angus	Raised beaches of ORS material	Sandy loam	Brown forest soil
Corby/Boyndie	97	943 (E) 3 (SE)	Moray & North East river valleys	Fluvioglacial deposits of acid schists and granite	Sandy loam/loamy sand	Humus iron podzol
	98	471 (E)	North East river valleys	Fluvioglacial terraces	Coarse	Humus iron podzol
Countesswells	115	820 (E)	Aberdeen	Granite till	Sandy loam	Humus iron podzol
*Darleith	147	138 (E) 178 (SE)	Fife & Angus	Basalt till	Loam	Brown forest soil
Darvel	163	36 (E) 196 (SE)	Distributed throughout, south of the Tay	Fluvioglacial deposits of Carboniferous material	Sandy loam	Brown forest soil
Forfar (closely related to Balrownie)	239	302 (E) 4 (SE)	Angus	Fluvioglacial and colluvial deposits of ORS material	Sandy loam/ loam	Humus iron podzol
Foudland	243	878 (E) 32 (SE)	Banff & Buchan	Dalradian schist till	Sandy loam/ loamy sand	Humus iron podzol
Hobkirk	296	317 (SE)	Merse	ORS sandstone till	Sandy loam	Brown forest soil
Insch	316	257 (E)	Aberdeen	Mixed till of gabbro and schist	Sandy loam/clay loam	Brown forest soil
Kilmarnock	331	210 (SE)	East Lothian	Carboniferous till	Loam over clay loam or clay	Brown forest soil with gleying
*Mountboy	414	214 (E) 70 (SE)	Angus	Carboniferous sandstone and lava till	Sandy loam/loam	Brown forest soil with gleying
*Winton	444	92 (E) 412 (SE)	Lothians and Fife	Carboniferous till	Sandy loam/loam	Brown forest soil with gleying
	445	444 (E) 1061 (SE)	Lothians and Fife	Carboniferous till	Loam/silty clay loam over sandy clay loam	Brown forest soil with gleying
*Sourhope	472	405 (E) 324 (SE)	Fife	ORS lava till	Loam	Brown forest soil
*Stirling	488	216 (E) 261 (SE)	Carses of Stirling and Gowrie	Estuarine and lacustrine deposits	Silt loam/silty clay	Non-calcareous gley
Tarves	517	629 (E)	Aberdeen	Mixed till of acid and basic igneous rocks	Sandy loam/sandy clay loam	Brown forest soil
Whitesome	575	310 (SE)	Merse	Carboniferous and Silurian till	Clay	Brown forest soil with gleying

harvested crops may not be ideal choices because of difficulties in harvesting. The level of yield is high but less consistently obtained than on Class 1 land due to the effects of minor limitations affecting cultivation, crop growth or harvesting. [Indeed, cereal yields from Class 2 land can exceed those from Class 1, owing to superior water supply] The limitations include, either singly or in combination, slight workability or wetness problems, slightly unfavourable soil structure or texture, moderate slopes or slightly unfavourable climate. The limitations are always minor in their effect however and land in the class is highly productive.

- **Class 3:** Land capable of producing a moderate range of crops. Land in this class is capable of producing good yields of a narrow range of crops, principally cereals and grass, and/or moderate yields of a wider range including potatoes, some vegetable crops (e.g. field beans and summer harvested brassicae) and oil-seed rape. The degree of variability between years will be greater than is the case for Classes 1 and 2, mainly due to interactions between climate, soil and management factors affecting the timing and type of cultivations, sowing and harvesting. The moderate limitations require careful management and include wetness, restrictions to rooting depth, unfavourable structure or texture, strongly sloping ground, slight erosion or a variable climate. The range of soil types within the class is greater than for previous classes.
- **Class 4:** Land capable of producing a narrow range of crops. The land is suitable for enterprises based primarily on grassland with short arable breaks

(e.g. barley, oats, forage crops). Yields of arable crops are variable due to soil, wetness or climatic factors. Yields of grass are often high but difficulties of production or utilisation may be encountered. The moderately-severe levels of limitation restrict the choice of crops and demand careful management. The limitations may include moderately-severe wetness, occasional damaging floods, shallow or very stony soils, moderately-steep gradients, erosion, moderately-severe climate or interactions of these which will increase the level of farming risk.

(Descriptions from Bibby et al., 1991, with additional material in square brackets).

It is useful to subdivide Classes 3 and 4 into 3₁, 3₂, 4₁ and 4₂, to provide more precise information on the likely proportion of short-term grass (leys) in the rotation, which varies from: "short grass leys common" (3₁) to "primarily grassland with some potential for other crops" (4₂).

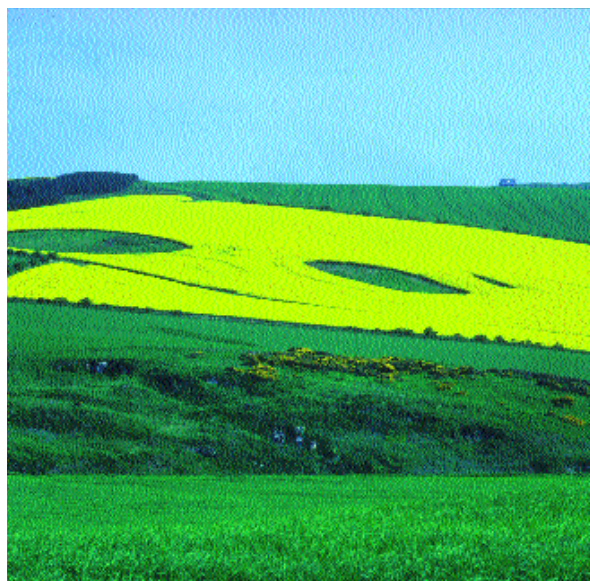
Only 0.2% (4,100 ha) of the arable land of Scotland is of Class 1, located along the north west coast of East Lothian, and in one continuous block of 1700 ha to the north of Carnoustie in Tayside (Angus), known locally as "the golden mile". In the Tweed Valley, the Lothians and Tayside, continuous areas of Class 2 land make up around half of the arable area, and they are associated with substantial components of Class 3₁. At the upper altitudinal limit of these areas, there are large fringes of Class 3₂ and 4 (see the maps in Brown & Shipley, 1982; Walker et al., 1982). Fife and lowland Moray are mosaics of Classes 2 to 4, reflecting their more complex geologies and topographies, whereas the potential arable land in Aberdeenshire and the Stirling area is predominantly of Class 3. Over Scotland as a whole, there are 172,000 ha of Class 2

land (7.9% of the arable area); 459,000 ha of Class 3₁ (21.1%); 714,000 ha of Class 3₂ (32.9%); 369,000 ha of Class 4₁ (17.0%); and 453,000 ha of Class 4₂ (20.1%). All the Class 1, and most of the Class 2 land, is in the East of Scotland.



Seed potato production on Class 2 arable land formed on till of ORS sediments, and carseland sediments. Strathearn near Perth.

4. THE CROPS



Oilseed rape and cereals, The Merse

Crop Rotations

By the nineteenth century, a wide range of local arable crop rotations had evolved; these were designed to maintain soil fertility, to control weeds and diseases, to improve soil structure, and to generate marketable as well as subsistence products. The classic Norfolk “four course” rotation, imported from England by the Improvers, developed into, for example, a “six course” rotation (wheat, roots, barley, hay, oats, potatoes) on the best land of the Lothians. Simpler arable rotations were used elsewhere and short-term grassland played a major role on Class 3 and 4 land. With the increasing use of inorganic fertilisers and chemical methods of controlling plant pests and diseases, the trend in the twentieth century has been towards rotations of cereals only, although some other sequences have tended to persist (e.g. wheat after potatoes in the South East to

make use of high levels of available potassium and phosphorus). By the 1940s, the area of oats had begun to decline sharply with the replacement of the horse by the tractor, and in some areas, the role of short-term grass has diminished to the extent that soil structure has deteriorated. However, where seed potatoes are a component of the cropping system, a break of up to eight years is still required for phytosanitary reasons. In recent years, apart from the introduction of oilseed rape, the most marked change has been from spring-sown to autumn-sown cereals, giving higher yields (greater interception of solar radiation; Hay & Walker, 1989) and better soil conditions at earlier harvest (see Chapter 2). This appears to have had a major effect on farm wildlife, owing to the removal of the food sources associated with overwintering stubble (see sustainability issues in Chapter 5).

The Crops of the East of Scotland

The distributions of crops grown in the East of Scotland, including short-term grass, for the harvest years 1988 and 1997 are shown in Table 4.1 and Figures 4.1, 4.2. These show the clear predominance of barley, grass leys and wheat, with no other crop occupying 10% of the arable area.

Comparisons between the two seasons reveal the following trends:

- a small increase in the total arable area, although this is reversed by the proportion of “set aside” (Table 4.1);
- a relatively small increase in the wheat area (Figure 4.2) (masked in Figure 4.1 by the increase in arable area);

Figure 4.1a Percentage areas of major crops in the East of Scotland, harvest 1988

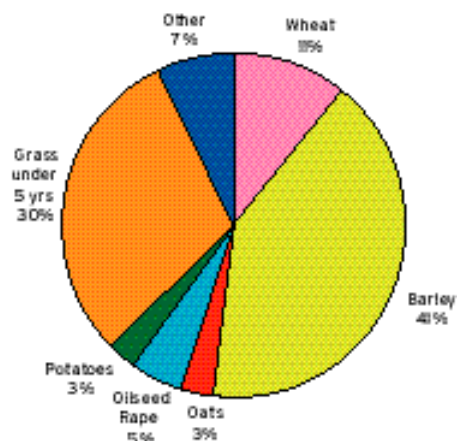


Figure 4.1b Percentage areas of major crops in the East of Scotland, harvest 1997

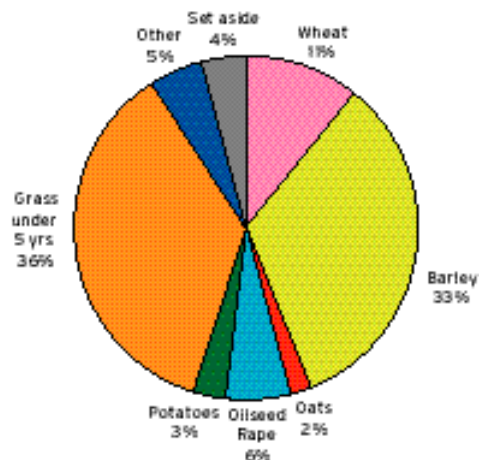


Figure 4.2a Percentage areas of major crops in the East of Scotland (excluding grass) harvest 1988

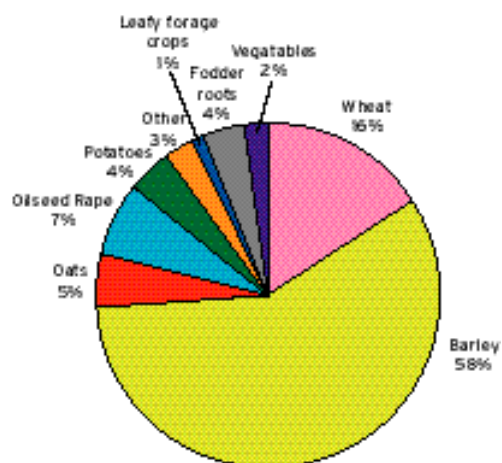
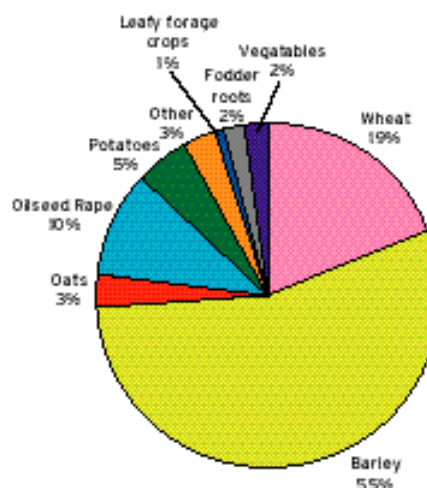


Figure 4.2b Percentage areas of major crops in the East of Scotland (excluding grass) harvest 1997



- substantial decreases in the areas of barley (Figures 4.1,2), offset by increases in areas of grass under 5 years (now the most extensive crop), and the inclusion of "set aside" areas;
- modest increases for oilseed rape, after a spectacular rise from zero in 1980;
- the collapse of other alternative arable crops (linseed, grain legumes) (Table 4.1)

which, unlike oilseed rape, have proved difficult to match with the Scottish climate (Taylor & Morrice, 1991; Hay, 1993) and the agribusiness sector (see also Appendix 4);

- stability in the potato sector; and
- a fall in the proportion of permanent grass on arable farms (Table 4.1).

Table 4.1 Total areas of crops and short-term grass in the East of Scotland, 1988-97

Crop	Mean 1988-97 (ha)	% change 1988-97
Wheat	103,504	+ 8.6
Barley (spring and winter)	294,125	- 10.1
Oats (spring and winter)	21,684	- 41.8
Oilseed rape (spring and winter)	50,074	+ 43.1
Linseed	1,461	- 79.4
Other cereals	1,486	+ 25.0
Potatoes	25,572	+ 0.2
Combinable peas and beans	4,637	- 73.3
Leafy forage	7,441	- 13.3
Fodder roots	18,449	- 49.5
Vegetables for human consumption	10,442	+ 28.3
Fruit	2,588	- 28.8
Other	7,065	+ 34
Total crops and fallow	566,038	+ 0.1
Set aside	20,351	+ 46.0
Grass under 5 yrs	280,747	+ 24.4
Grass over 5 yrs	232,174	- 20.9
Total crops and grass	1,078,953	+ 0.7

Source: AEFD (1999a) and the DAFS census data for 1988.

Table 4.2 presents the areas of crops in the East of Scotland in 1997 as a proportion of the Scottish total, emphasising the concentration of arable agriculture in the East.

Table 4.2 Proportions of Scottish arable crops grown in the East of Scotland, harvest 1997.

Crop	Scottish total (ha)	East of Scotland Total (ha)	Percentage in East of Scotland
Wheat	108,655	101,360	93.3
Barley	344,105	294,293	85.5
Oats	21,185	16,182	76.4
Other cereals	2,489	1,766	70.9
Oilseeds and linseed	59,855	56,950	95.1
Potatoes	27,613	25,627	92.8
Fodder crops	29,386	21,738	74.0
Vegetables	11,701	11,422	97.6
Fruit	2,408	2,241	93.1
Total crops	607,397	573,495	94.4
Set aside	40,175	36,237	90.2
Short-term grass	1,101,926	509,578	46.2
Total crops and grass	1,709,323	1,083,053	63.4

Source: AEFD (1999a,b)

Yields and Yield Potential

Cereals

The yield of a particular crop depends upon genotype, management, season and land capability class, and their interactions. For example, in a survey of nearly 500 farm crops of spring barley in the East of Scotland over five seasons, 1978-82 (Hay, Galashan & Russell, 1986), there was a very wide range of farm yield from 1.2 to 7.8 t ha⁻¹ (at 15% m.c.). However, national and international statistics have tended to indicate that cereal yields on farms in Scotland tend, on average, to be higher not only than those in other northern countries (e.g. Table 1.1) but also than in England and Wales.

This phenomenon was first investigated experimentally in 1976 and 1977 by comparing the growth and physiology of two spring barley varieties under the same management at Cambridge (52°11'N) and Pathhead near Edinburgh (55°53'N) (Kirby & Ellis, 1980; Ellis & Kirby, 1980). Over the two contrasting seasons (severe drought in 1976), the grain yields of the Pathhead crops were 79% higher than at Cambridge; the differences could be explained in terms of up to 64% higher ear population densities, up to 17% more grains per ear, and up to 20% higher individual grain weights. It was concluded that the longer

photoperiods (more than 15 hours from mid-April to late August) and lower temperatures at Pathhead (i.e. similar supplies of solar radiation distributed over longer days; Chapter 2) permitted longer durations of each developmental phase, and longer growing seasons overall. In consequence, more organs (tillers, ears, spikelets, florets) were initiated and/or fewer organs aborted; and there was greater interception of solar radiation to support these organs.

This provided the first unequivocal support for the hypothesis that the yield potential of adapted crops, such as spring barley, can be higher under cool long days, although it should be noted that not all comparisons give such clear results (e.g. Ellis & Brown, 1986). Since then, there has been a series of experiments at different latitudes in Scotland, England and France, designed to investigate the environmental control of development and yield in wheat (e.g. Kirby et al., 1987; Porter et al., 1987; Delécolle et al., 1989; Hay & Delécolle, 1989). The concept of slow and prolonged development, with extended grain filling, delayed senescence and enhanced interception of radiation, explains why Midlothian holds the world record for the yield of a field crop of wheat (as opposed to small plot yields) at 14 t ha⁻¹ (Hay, 1993).

A study was conducted in the early 1980s (Hay et al., 1986; Hay & Galashan, 1988) to

Table 4.3 The yields of cereal crops (t ha⁻¹ at 15% m.c.) in the South East of Scotland, 1978-82.

	Spring Barley	Winter Wheat
All farms	4.7 (474)	n/a
Specialist arable farms	5.0 ± 0.06 (265)	5.9 (149)
Variety trials	5.6 ± 0.21 (110)	6.4 (48)
Calculated maximum potential	9.2	13.2

Values are means over five seasons ± s.e. with number of farms in brackets (adapted from Hay et al., 1986).

examine the extent to which farmers in Scotland were exploiting the relatively high yield potential of existing approved varieties of the major arable crops. The data for comparison were:

- Actual farm yields from unpublished data in the annual Farm Accounts Survey (a representative sampling of 3% of Scottish farms carried out by the Department of the Scottish Executive which is now called the Rural Affairs Department, RAD - formerly DAFS and AEFD - see Appendix 3);
- Yields, under optimum conditions and a very high level of management, from the annual variety (value for cultivation and use) trials carried out by the Scottish Agricultural College (SAC); and
- Maximum potential yields for the East of Scotland, calculated using a standard radiation interception model, and representative dates for sowing and harvest.

The main findings of these comparisons were:

- There was very little difference between farm types in the actual barley yields obtained, with specialist farms performing no better than mixed enterprises (Hay et al., 1986); the difference between all farms and specialists was mainly due to low yields on Class 4 land;
- On average, arable farmers achieved 90% of the barley variety trial yields, even though the trial data were from plot experiments under very intensive management (i.e. the yield levels were effectively indistinguishable from the variety trial levels);
- On average, farmers were achieving 54% of the potential yield of spring barley, and 45% of the potential of winter wheat, indicating that there is considerable scope for yield improvement on farms. Nevertheless,

Table 4.4 The yields of combinable crops (t ha⁻¹ at 15% m.c.) in the East of Scotland, 1993-97 (with separation of results into the SAC East and North areas)

	SAC area	Mean farm	Highest farm	Mean variety trial	Highest variety trial	Max. Potential
Spring barley	E	5.5	Not det.	7.6	9.3	9.2
	N	4.7	~8	7.5	8.7	8.8
Winter barley	E	6.3	9.5	10.5	11.1	13.2
	N	5.4	8.2	8.9	10.4	12.5
Winter wheat	E	8.2	10.8	11.2	12.3	13.2
	N	6.9	9.8	9.8	11.1	12.5
Spring oats	E	5.2	7.9	7.3	8.5	9.2
	N	4.4	7.1	6.9	7.2	8.8
Winter oilseed rape	E	3.0	4.7	5.5	5.7	n/d
	N	2.1	4.1	4.8	5.6	

Values are means over five seasons

the highest recorded farm yields were 8.6 t ha⁻¹ (93% of potential) for spring barley and 10.7 t ha⁻¹ (81%) for winter wheat.

This exercise was repeated for the harvest years 1993-97 for this booklet, and the results are presented in Table 4.4.

From these data, the following conclusions can be drawn:

- For spring barley, farm yields have risen slightly over 15 years (around 10%) but there has been a very substantial increase in variety trial yields (36%); the highest variety trial yields are now approaching the yield potential;
- These findings for barley can be interpreted in terms of two factors: i) replacement of spring barley by winter barley on land of higher capability; ii) reduction in inputs on land of lower capability (Chapter 3), so that less use is made of the potential yield of new spring barley varieties; it should also be noted that farm yields might have been expected to rise more steeply with the replacement of the "aged" malting variety Golden Promise by newer varieties (many also of malting potential) of much higher yield potential;
- For winter wheat, which is grown on land of high capability, the developments of 15 years have resulted in increases of around 30% in farm yield and over 60% in variety trial yield, suggesting a degree of de-intensification of the crop on Scottish farms;
- The exploitation of the yield potential on farms was: 53-60% (spring barley); 43-48% (winter barley); 55-62% (winter wheat); 50-56% (spring oats);

- Farm yield of winter barley was 0.7-0.8 t ha⁻¹ higher than that of spring barley, whereas the variety trials indicated an advantage of 1.4-2.9 t ha⁻¹.

With the limited amount of available data, it is not yet possible to evaluate oilseed rape in the same way, although farm yields do appear to be relatively low compared with variety trial data.

The inputs required to achieve the yields in Tables 4.3 and 4.4 are considered in detail in Chapter 5.

Potatoes

Parallel studies of the actual and potential yield of potato crops in Scotland (Hay & Galashan, 1989) were less conclusive because of the many technical obstacles, including: estimation of field leavings and losses in store and handling; less precise farm records; variation in the dry matter content of tubers; the aggregation of statistics for early, seed, ware, and combined enterprises; variation in the minimum size of harvested tubers etc. Provisional conclusions for the period 1978-



Potatoes, near Kinross

82 were different from those for cereals: specialist arable farmers were better than average at exploiting the potential of the crop (e.g. a mean over five years of 36 t ha⁻¹ fresh weight > 30 mm, compared with 31 t ha⁻¹ for other arable farms in the South East) but these yields were well below those achieved in corresponding variety trials (53 t ha⁻¹). At 36 t ha⁻¹, specialist farm yields represented only 44% of the maximum potential yield of 81 t ha⁻¹ (here calculated by the methods of MacKerron & Waister (1985); MacKerron, (1985, 1987); which have subsequently been improved to include the effects of water relations (Jefferies & Heilbron, 1991; Jefferies et al., 1991)). Nevertheless, unpublished results of MacKerron suggest that some specialist farmers did achieve yields close to the potential in 1983-85.

A repeat of the analysis for the years 1993-97 shows that there has been no increase in mean farm yield over 15 years; this is consistent with the lack of improvement in yield potential of potato varieties, as opposed to improvement in tuber quality and disease resistance. Unlike determinate crops such as cereals, there is no consistent evidence that the potential yield of the potato crop increases with latitude (Hay & Galashan, 1989). The benefits that the cool climate of Eastern Scotland bring are more those of crop health: lower populations of virus-transmitting aphids are the foundation of the Scottish seed potato industry (as well as specialist enterprises such as growing virus-free Narcissus bulbs).

Grass Crops

Potential growing seasons are normally expressed in terms of the annual duration (time or thermal time/degree days) of temperature above a threshold (commonly 5 or 6°C; Chapter 2). In humid climates such as Scotland's, such calculations must be modified to take account of soil water

relations (Hay, 1993). Thus the actual growing season for an arable crop which is planted and harvested (first soil moisture deficit to return to field capacity) tends to be shorter than the potential growing season, although this can be overcome to some extent by choosing autumn-planted rather than spring-planted crops. This analysis leads to the question of whether perennial crops would exploit the potential growing season better than annuals in those areas in which the water relations are limiting. In Scotland, there is, at present, only one candidate for this role: grassland, normally based on perennial ryegrass, with or without white clover; the increase in area of grass on arable soils over the last fifteen years confirms its importance.

The ceiling for potential yield of grassland in the United Kingdom, established from investigations in Northern Ireland, is around 25 t DM ha⁻¹ (Adams et al., 1983); but the yield of no other major crop is so dependent upon the environment and management (principally nitrogen nutrition, water relations, harvesting method and timing, as well as temperature and irradiance; Hay & Walker, 1989). Indeed, it is difficult to make meaningful comparisons among systems and areas because of the lack of standard methods of measurement (Hodgson et al., 1981; Hay & Walker, 1989). Another issue which has yet to be thoroughly explored is the extent to which the combination of long photoperiods and cool temperatures stimulates the growth and yield of pasture swards as opposed to spaced plants (see, for example: Hay, 1989, 1990; Hay & Heide, 1984; Hay & Pederson, 1986; Junttila et al., 1990; Solhaug, 1991).

Where grass is grown on Scottish arable land it is normally for one of two reasons. First, on Class 3, and especially Class 4 land, short-term grass permits the intensive exploitation of areas with difficult water relations (short actual growing season for

planted crops) or problems, for example, of slope or stoniness. Secondly, on Class 2 land of coarse texture or vulnerable structure, inclusion of grass in the rotation may be necessary to maintain the organic matter content, and the associated fertility. The products are silage, increasingly in the form of “big bales”, and grazing. In neither of these situations can the crop approach the yield potential for cut perennial ryegrass swards. Higher yields can be expected, by contrast, on farms managed intensively for dairy production. Representative yields (generally less than 10 t DM ha⁻¹) for a range of grassland enterprises, at different levels of management, can be found in the tables from the SAC Farm Management Handbook (Chadwick, 1999).

Overview

This brief review, and the economic details presented in Appendix 4, show that

- the East of Scotland has the potential to give very high yields of adapted crops
 - the range of crops grown is largely determined by EU support schemes (for grain, dairy products and meat) - except potatoes, which benefit from the high plant health status of the area (see Appendix 4)
 - the range of species grown has tended to decrease over the last decade
 - very little of the crop production is for direct human consumption, as opposed to consumption via livestock or via industrial processes (notably alcoholic spirits)
 - a significant proportion of the arable area is unused (set-aside)
- Nevertheless, the mix of enterprises does vary considerably within the East of Scotland. For example, there is a greater emphasis on livestock in the North East whereas, in Fife and Angus, there is a more complex cropping pattern, which includes vegetables and soft fruit for direct human consumption.



Machine harvesting of raspberries, Blairgowrie

5. INPUTS AND SUSTAINABILITY



Timothy (*Phleum pratense*) grown for hay and seed, carselands west of Stirling

In evaluating the sustainability of cropping systems in the East of Scotland, it is important to start with the inputs required to sustain existing systems and yields (e.g. Tables 1.1, 4.3 & 4.4).

Inputs: Mineral Nutrition

The 1997 survey of fertiliser use in Scotland (MAFF, 1998) showed that the (mean) application of industrially-synthesised nitrogen fertiliser to arable crops and managed grassland has remained above 100 kg N ha⁻¹ for the last twenty years, with no sign of significant reduction. Levels of phosphorus and potassium application have also remained steady (around 70 kg ha⁻¹ phosphate and potash on arable crops; 30 - 40 kg of each on grassland), even though the reserves of available phosphate in many Scottish soils would justify reduced applications. Unless there are marked and rapid changes in the physiology of varieties

(e.g. genetic modification to incorporate nitrogen-fixing genes), in plant/microbial relations (e.g. more effective mycorrhizal associations) or in potential yield on lower grade land under "organic" systems, the maintenance of existing yields will necessitate similar applications of N and K for the foreseeable future. The exception is the potato crop which could be managed with much lower inputs of nitrogen (Hay & Walker, 1989), if the aim were dry matter, rather than fresh weight, yield.

The continued availability of these mineral resources depends upon world supplies and prices of fossil energy, global security, and the size of global potash and phosphate deposits, although there could be some substitution by increased reclamation of agricultural waste. There are serious doubts about the capacity of known phosphate deposits to meet world demand, although, in the UK, the "mining" of existing soil reserves could delay any crisis; and there is at least the potential for utilising domestic sewage, if problems of contamination by heavy metals and microbial pathogens are overcome. Soils in humid areas such as Scotland will require regular and heavy liming at least once per decade for the foreseeable future to maintain yield capacity; there are very extensive deposits of useable limestone in the UK and elsewhere, but their exploitation contributes to climate change and degradation of the environment. The frequency of liming will depend upon the types of nitrogen fertiliser used (ammonium-based products accelerate acidification) and levels of atmospheric pollution (acid rain).

One important consequence of these heavy inputs, and the additional inputs to

livestock production in the form of imported feed, is that there is a serious risk of pollution of non-agricultural areas, by various forms of nitrogen (most seriously gaseous ammonia, and nitrate), phosphate in solution, and effluents with a high biological oxygen demand. The consequences of such pollution, both acute and chronic, can be the sterilisation or eutrophication of water bodies, the pollution of drinking water, and the artificial fertilisation of terrestrial plant communities. These effects are in addition to those resulting from the relevant manufacturing activities.

Inputs: Crop Protection

The protection of crops growing in Scotland is much more complex than mineral fertilisation, as the incidence and importance of pests and diseases varies with crop species, variety, location and with time. Crop protection is an unremitting struggle against a wide range of rapidly-evolving pathogens (viruses, bacteria, fungi, nematodes, molluscs, insects and other arthropods), affecting all stages from the seed, through vegetative and reproductive phases, to harvest and storage. The following case histories for the major Scottish crop, barley, are necessarily illustrative rather than comprehensive.

The struggle is typified by seed-borne fungal diseases of barley. As resistance to routinely-applied organo-mercury fungicides built up in the 1980s, there was an epidemic of barley leaf stripe (*Pyrenophora graminea*), a disease which formerly caused serious yield losses, but which most Scottish farmers of the present generation could not recognise from its symptoms in the field. By 1990, the fungus was found in more than 80% of seed stocks of spring barley, and was a major threat to Scottish agriculture. Yet, within two years,

the epidemic had been brought under control by ensuring that all seed with more than 4% infection was treated with an effective fungicide before planting (Cockerell et al., 1995).

Crop protection must change with the evolution of systems of crop management. For example, before the introduction of winter barley, the spring crop was sown in March or April and harvested in late summer; for six months there was no green crop. The move to winter cropping in the early 1980s created a "green bridge" of crop plants or volunteers throughout the calendar year, which could act as reservoirs of barley diseases. This has led to an increase in the incidence of traditional fungal diseases of green tissues, (powdery mildew *Erysiphe graminis*; net blotch *Pyrenophora teres*; and rhynchosporium *Rhynchosporium secalis*) but also less familiar diseases such as snow rot (*Typhula incarnata*) which can develop on winter barley during the winter months. Thus, in the pursuit of higher yield potential (greater interception of solar radiation), farmers have encountered increased disease pressure.

There can be important interactions between varietal characters and disease. In the 1990s, spring barley varieties (e.g. Chariot and Derkado) were introduced which were resistant to powdery mildew. As this was the most common foliar disease at that time, it was hoped that fungicide usage would fall sharply, but these mildew-resistant varieties turned out to be susceptible to rhynchosporium: the solution of one disease problem permitted another to take the dominant position. Control of rhynchosporium is now causing concern, as no current fungicide is effective alone, and resistance to some groups of fungicide is developing.

Fungal diseases predominate in cereals (see

Table 5.1), but there are major arthropod pests. Wheat bulb fly (*Delia coarctata*) is a common pest in the South East of Scotland, causing “deadheart” symptoms when larvae feed on the main shoot. Since the eggs which will result in damage in spring are deposited during the preceding summer, preferentially on bare soil, the greatest risk is run by winter wheat crops after potatoes, peas, oilseed rape or set-aside. There is a long history of wheat bulb fly damage in East Lothian, Fife and Angus, but since the early 1990s there has been an increase in the number of eggs recorded, and in the range of the pest (e.g. to the Merse) (Evans, 2000). This suggests that its incidence and severity may be changing in response to changes in climate and/or farming practice (e.g. set-aside and increased areas of oilseed rape). Without an effective forecasting system, many farmers will continue with prophylactic, and in many cases unnecessary, insecticide applications (see Table 5.1).

Of the main crops in the East of Scotland, the potato is most susceptible to the full range of pathogenic taxa, including an array of viruses transmitted by leaf-feeding aphids (e.g. the peach-potato aphid *Myzus persicae*); bacterial diseases such as blackleg (*Erwinia carotovora*); foliar fungal diseases, notably late blight (*Phytophthora infestans*); soil-borne nematodes (potato cyst nematodes (PCN) *Globodera* spp.) as well as a wide array of fungal and bacterial diseases of tubers in storage. By exploiting the cool climate of the North of Scotland (slow build up of aphid populations) and a comprehensive set of strict regulations (restriction of cropping to PCN-free land; regular field inspections; pre- and post-harvest diagnosis of virus diseases etc.), Scotland maintains a highly-profitable seed tuber industry, supplying many overseas countries, particularly in the Mediterranean zone. Nevertheless, this phytosanitary approach does not rule out the need for extensive chemical crop protection (e.g.

Table 5.1 Estimates of the total usage of pesticides on cereal crops in Scotland, 1994, 1996 and 1998

	1994	1996	1998
Insecticides			
Pyrethroids	15,210	46,456	56,648
Organophosphates	31,608	15,656	20,993
Organochlorines	-	-	1,157
Carbamates	4,192	1,962	2,650
Unspecified or mixed formulation	-	427	-
All insecticides	51,010	64,501	81,448
Molluscicides	17,025	8,841	30,586
Fungicides	1,092,222	1,712,768	1,967,309
Herbicides	1,011,474	1,315,092	1,354,105
Growth regulators	295,233	388,787	422,748
Seed treatments	779,010	830,133	799,005
All pesticides	3,245,974	4,320,122	4,655,201
Area planted (ha)	395,286 ha	449,298 ha	468,153 ha

The data are expressed in terms of “spray hectares of active ingredients”.

Source: Pesticide Usage in Scotland Reports. Arable Crops 1994, 1996, 1998. Edinburgh: Scottish Agricultural Science Agency.

aphicides, protection against blight).

Each crop species and cropping system has its own characteristic weeds, some of which can be extremely difficult to control (e.g. wild oats, which are taxonomically, and therefore biochemically, close to the major cereal crops). Weeds are controlled by routine spraying with the appropriate selective herbicide (Table 5.1), although all weeds can be controlled by a combination of rotation and cultivation. Recent work on low doses of herbicide, repeated only if necessary, has demonstrated how herbicide usage can be reduced without compromising crop yield and quality.

The extent of pesticide applications to control the pests, diseases and weeds of cereal crops in Scotland is shown in Table 5.1 (Note that several of the values for “spray areas” are greater than the actual area cropped because many crops receive two or three applications per season). The preponderance of herbicide and fungicide applications reflects the practical problems of cereal growing in a cool climate, but the data also show a distinct rise in the use of insecticides, which may be related to climate change (increased winter survival and higher spring populations of insects). Work on integrated farming systems has demonstrated some of the ways in which pesticide applications can be reduced. Nevertheless, there is no immediate prospect of a substantial reduction in the level of application of pesticides, if existing yields are to be maintained.

Risks to humans from pesticides applied according to codes of best practice, are judged to be low, and the accumulation of pesticide residues in the human diet is monitored by government scientists to ensure food safety. On the other hand, pesticides inevitably have a deleterious effect on biodiversity in crops and their margins.

Inputs: Energy

Fossil fuel is required for the chemical synthesis of fertilisers and pesticides; for the transport and distribution of agrochemicals and other supplies; for traction (direct fuel use); and for the manufacture of machinery; before any account is taken of the large energy costs of transforming, transporting and marketing the farm yield into food or other products. For example, Slessor (1975) calculated that the fossil energy required to meet the direct fuel use, fertiliser and pesticide needs of a Scottish spring barley crop was equivalent to around 20% of the solar energy captured in the harvested grain; with the intensification of cereal production, these energy costs will be at least as high now. Intensive agriculture, as presently practised worldwide, needs to be primed with oil to secure the acquisition of solar energy (see the pioneering studies of Pimental & Pimental, 1979).

Implementation of the Kyoto Protocol on greenhouse gas emissions may have a significant effect on the volume of agricultural produce which is transported over long distances, particularly commodities with a high moisture content. The competitiveness of agriculture in the East of Scotland might benefit from any such change.

Predictable Change

The next step in evaluating the sustainability of arable agriculture in Scotland is to review predictable changes in the physical and biological environment, and their potential impacts.

Current forecasts of long-term climate change in Scotland are for higher temperatures (typically 1 - 3°C) particularly in winter, higher winter rainfall, and drier

summers (Kerr et al., 1999). As the length of the growing season for arable crops is largely determined by the duration of soil moisture deficits (Chapters 2,4), the actual effect on cropping systems will depend upon the amount and distribution of winter precipitation. In this context, drainage may play a central role. Many of the productive arable soils of Scotland are inherently poorly-drained (brown forest soils with gleying; and non-calcareous gleys; Table 3.1; Figure 3.2; Appendix 2), and mechanised agriculture is possible only with under-drainage, much of which was installed in the nineteenth century using cheap manual labour. This drainage infrastructure is now deteriorating, and it remains to be seen whether its renewal can be justified as cost-effective under the increased loading brought on by higher winter precipitation. Poor drainage could have major impacts, not only on growing season length, but on the grazing of rotational grassland by livestock.

Summer drought may also pose increasing problems, particularly for spring crops grown on soils of low available-water capacity in the drier parts of the East of Scotland. The scope for increased irrigation is limited, since additional supplies would have to come from rivers which are already heavily exploited in dry years.

Large areas of the South East have been under intensive cultivation continuously since the thirteenth century, when the great Cistercian abbeys of Newbattle and Melrose were established, and they have continued to provide high yield under each succeeding system of management (Meiklejohn, 1951). There is little sign of deterioration in “performance”, in spite of a general decrease in soil organic matter, which tends to increase susceptibility to erosion and loss of structure, as well as lowering the ion-exchange capacity.

Organic matter levels can be restored by increasing the return of crop residues and manure, and keeping soil disturbance by cultivation to the minimum necessary for establishment and weed control. There is evidence of soil erosion on steeper slopes in Southern Scotland from as early as the Bronze Age (Mercer & Tipping, 1994), but this is unlikely to be a factor in the lowlands even under increased winter rainfall. If summers do become significantly drier, erosion of poorly-structured arable soils on the North-East coast (Figure 3.1; Appendix 2), by wind-blow, could intensify. In summary, the soils of the East of Scotland are generally robust, as long as soil structure is maintained.

Considering biological effects, as outlined above, the rate of evolution of pathogens of existing agricultural systems is so rapid that predictions of developments under climate change are of little value. Although warmer winters should increase pathogen pressures on all crops, the first effects will probably be to endanger the health status of Scottish seed potatoes, owing to earlier and higher populations of virus-transmitting aphids. The industry cannot migrate much further north.

Nevertheless, taking a historical perspective over the last two hundred years, farming systems in the area have demonstrated a capacity to survive climatic variation of the scale predicted for the next 50 years. For example, Figure 2.2 shows a five-fold variation in late summer rainfall over the last forty years. This may justify the judgement of Kerr et al. (1999) that climate change is unlikely to be a major factor modifying agricultural production; and, of course, Scottish agriculture could play a part in the alleviation/reversal of climate change (e.g. generating biofuels; short rotation coppice etc.). It has been estimated that around one quarter of the arable area of Scotland would be needed to

produce the equivalent of the amount of diesel used in its farming systems – similar to the proportion needed to produce oats for horse power before 1950.

Compared with the threats posed by climate change, those posed by world prices and supplies of oil and minerals are probably of much greater magnitude. Other major factors, whose futures are difficult to predict include:

- Major advances in biological understanding, and in the tailoring of species and varieties for yield and quality
- Fundamental advances in applied biology (e.g. managed mycorrhizal associations)
- Unexpected substantial climatic changes (e.g. major alterations in the circulation of the atmosphere or of the Atlantic Ocean) and damaging instability in weather
- Major changes in the patterns of world trade, including EU (e.g. the candidature of Eastern European countries) and WTO arrangements
- Serious deterioration in global security
- Major changes in diet, consumer demand and in the marketing of agricultural products
- Depression of yield by pollution (e.g. regional effects of ozone)
- Major reverses in the struggle against crop pathogens
- Policy decisions for the countryside favouring management for the production of environmental goods (low pollution; energy; aesthetics; access; recreation) or the products of forestry

Sustainability: Prospects for Arable Land in Scotland over the Next 50 Years

Sustainability is used here as defined by Brundtland: “meeting the needs of the present without compromising the ability of future generations to meet their needs” (World Commission on Environment and Development, 1987).

Arguing from a historical perspective; taking the current predictions of climate change into account; assuming a continued high level of national prosperity; and narrowing the focus to the East of Scotland; the signs are that the current approach to land use could be sustained over the next 50 years. Its continuation would be favoured by actions to reduce pollution, recycle resources, and actively alleviate environmental change. Nevertheless, there would be a need to respond quickly, in the short term, to changes in the global economy; to the evolution of crop pathogens; and to pressure from consumers. Although these predictions indicate the survival of Scottish



Export of Scottish seed potatoes from Montrose

agriculture, they do not necessarily indicate the survival of rural (human) communities and institutions, and landscape quality.

However, no country is an “island”, and policies for Scotland must be set in a world context. Taking a fully-global perspective (rather than simply considering world prices), and taking account of the population/food equation, increases in the extent and intensity of food production are both essential and intrinsically unsustainable: necessary on ethical grounds, but ultimately causing irreversible planetary changes. This is the basis of the concerns over genetically-modified (GM) crops and food expressed by Sir Robert May, the UK government chief scientist (May, 1999): at present not all of the potentially-cultivable land in the world is used, and over 30% of the food produced is lost to pathogens and spoilage (Evans, 1996). Cultivation of new land, increased yield, and reduced losses (e.g. by the use of GM technology) are all about reducing the share of solar radiation captured by photosynthesis which is consumed first by species other than man - be they rats, rabbits, locusts, fungi or bacteria, - or pandas, chimpanzees, songbirds or termites. Thus, progressive increases in the extent and intensity of agricultural production will inevitably cause reductions in biodiversity. Taking an example close to home, the recent sharp decline in farmland birds in the UK has been attributed to the ploughing-in of cereal stubble in the autumn, thereby placing an important food resource out of reach of a range of wild species.

The consequences of changes to agriculture on the environment are rarely simple and concern has been expressed

that moves towards extensification and organic farming may not always provide the environmental benefits that are commonly predicted (Kirchmann and Thorvaldsson, 2000). It is also increasingly recognised that actions taken to achieve one environmental goal may make another more difficult to achieve. For example, manure and slurry spreading contribute to the Europe-wide problem of ammonia emissions and the consequent increase in nitrogen deposition on the land surface. Research is needed to identify the consequences of changes in farming operations in different agro-ecological zones.

Arguments over intensification of food supply and biodiversity, of course, ignore the question of whether there are sufficient resources of oil, phosphorus, trace elements and water to go round; or whether the planet can absorb the load of pollution generated by intensified agriculture. There are other issues, such as the extent to which food should be processed through livestock. Nevertheless, if a population of 9 billion is to be fed (US Census Bureau projection for 2050) the world will be a very different place.

Recent Sources:

Agriculture and Technology Review, *The Economist*, 25 March, 2000;
 Briefing Ecology and Economics, *Nature* **395**, 426-434, 1998;
 Food Production, Population Growth, and the Environment, *Science* **281**, 1291-1292;
 The Greening of the Green Revolution, *Nature* **396**, 211-212, 1998;
 Crop Scientists Seek a New Revolution *Science* **283**, 311-316;
 Feeding the World in the 21st Century *Nature* **412**, C55-C58, 1999;

6. THE FUTURE: POLICIES FOR THE USE OF ARABLE LAND IN SCOTLAND OVER THE NEXT 50 YEARS



Virus-free Narcissus near Brechin, Angus

The information in this booklet can be summarised as follows:

- Scotland has a relatively small but robust area of arable land of very high potential yield for adapted crops
- This area is currently devoted predominantly to crops subsidised under the Common Agricultural Policy, now Agenda 2000, of the European Union; the products are mainly destined for livestock and alcoholic beverage production
- Scotland has a reputation for very high quality products for direct human consumption, principally soft fruit and potatoes (via the seed potato industry)
- For the best land, the financial margins for specialist crops such as carrots are good
- Nevertheless, unlike many other countries in Europe, the citizen cannot see her next meal in the fields near her home, and tends to have little interest in where her food supplies originate; a large proportion of the diet is imported
- (Not mentioned above, but crucial) Scotland has one of the poorest diets, and nearly the worst health record, amongst developed countries

Drivers for Change include:

- Climate change
- Agenda 2000
- Low farm incomes; world prices; exchange rates
- Need for environmental goods
- Customer perceptions: health, food safety, positive interest in eating
- Unrelenting scientific progress, including GM technology
- The Organic movement
- Vegetarianism
- Direct marketing by farmers
- Devolution

Policies for Agriculture in Scotland might, with benefit, be integrated with Policies for the Environment, including rural

communities, for Food, and for Health. There are precedents for this, including the recent integrated drive for improved health in Finland.

What is undoubtedly true is that scientists, including crop scientists, will play a major role in the future.

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Appendix 1: The “Scottish System” for Scientific Support to Natural Resource Use, Food and the Environment

The term “Scottish System” has been used in different ways for a number of purposes over the last century. At its simplest, it originally expressed the integration of education, development and extension for land use within the Scottish Agricultural Colleges (now SAC) – a model widely applied in North America and the former British Empire.

The term is now more widely used to express the coordinated activities of the organisations funded by the Scottish Executive Rural Affairs Department to work on research, development, education, extension, policy support, and public understanding of science, in relation to land and water use, food and the environment.

These institutes come together under the aegis of CHABOS (Committee of the Heads of Agricultural and Biological Organisations in Scotland) whose membership is:

Fisheries Research Services, Aberdeen and Pitlochry

Forestry Commission Research Agency, Edinburgh

Hannah Research Institute, Ayr (Dairy)

Macaulay Land Use Research Institute, Aberdeen (Environment)

Moredun Research Institute, Edinburgh (Animal Health)

Rowett Research Institute, Aberdeen (Animal & Human Nutrition)

Royal Botanic Garden, Edinburgh

Scottish Agricultural College, Edinburgh, Aberdeen & Ayr

Scottish Agricultural Science Agency, Edinburgh (Crops and Environment: Regulation)

Scottish Crop Research Institute, Dundee

There are also close functional relationships with the relevant academic departments of the Higher Education Institutes, particularly the Universities of Edinburgh, Aberdeen, Glasgow, and Dundee.

Appendix 2: Selected Soil Profiles from the East of Scotland

(representative profiles from Memoirs of the Soil Survey of Great Britain)

Brown Forest Soil		(Hobkirk Series formed on ORS, under arable cropping)
S	0 - 25 cm	Dark reddish brown sandy loam; weak blocky structure; friable; low organic content; occasional small stones; abundant roots; sharp change to
B ₂	25 - 51	Reddish brown sandy loam; very weak blocky structure; friable; frequent small sub-angular and sub-rounded stones; frequent roots; gradual change into
B ₃	51 - 76	Reddish brown fine sandy loam; massive structure; firm; frequent small stones; occasional roots; clear change into
C	76+	Weak red fine sandstone
Brown Forest Soil		(Darvel Series formed on fluvioglacial deposits, under arable cropping)
S	0 - 28	Dark brown sandy loam; weak medium crumb structure; very friable; low organic content; occasional small rounded stones; abundant roots; sharp change to
B ₂	28 - 43	Dark reddish brown loamy sand; weak fine blocky structure; very friable; low organic content, confined to worm burrows; mineral carbon present in coal-containing bands; occasional small stones; frequent roots; gradual change into
B ₃	43 - 76	Brown sand; single grain; loose; small rounded stones rare; occasional roots; gradual change into
C	76 - 117	Brown sand; single grain; no stones; roots rare; clear change to
C _g	117+	Brown sand; single grain; no stones; no roots; strong brown and light brown-grey mottles.
Brown Forest Soil with Gleying		(Winton Series formed on Carboniferous till, deciduous woodland)
L/F		Leaf litter
A	0 - 20 cm	Dark grey brown sandy clay loam; fine subangular blocky structure; friable; moderate organic content; abundant roots; occasional stones; earthworms active; clear boundary, but irregular due to worm activity
B _{2(g)}	20 - 38	Brown clay loam; coarse blocky structure; plastic; frequent roots; low organic content except in worm burrows; stones frequent; many reddish yellow mottles and grey-brown ped faces; gradual change into
B _{3(g)}	38 - 56	Reddish brown clay loam; coarse prismatic structure; plastic; occasional roots; frequent stones; many yellowish red mottles and light brown-grey ped faces; faint manganiferous staining; gradual change to

C _(g)	56+	Weak red clay; coarse prismatic structure; plastic; roots rare; frequent stones; faint yellowish red mottles and greyish ped faces and streaks; strong manganiferous staining
Brown Forest Soil with Gleying		
S	0 - 28 cm	(Whitsome Series formed on mixed till of ORS, Silurian and Ordovician sedimentary rocks, under arable cropping) Dark reddish brown clay loam; medium blocky structure; friable; low organic content; abundant roots; occasional small stones; clear change to
B _{2(g)}	28 - 53	Dark reddish grey clay loam; coarse prismatic structure; firm, plastic when wet; frequent stones; occasional fine roots; fine yellowish red mottles; gradual change into
B _{3(g)}	53 - 76	Dark reddish brown clay loam; massive structure; firm; frequent stones; roots rare; faint ochreous mottles; gradual change into
C _(g)	76+	As B _{3(g)} with abundant weathered fragments of mudstone and shale.
Humus Iron Podzol		
S	0 - 30 cm	(Boyndie Series formed on fluvioglacial sand, under arable cropping) Grey-brown loamy sand; incoherent structure; merging into
A ₁	30 - 50	Yellow-brown sand, yellow colour increasing with depth; loose cloddy structure, bound by fine roots; transitional horizon, merging into
B ₂	50 - 75	Yellow-brown sand; single grain structure; some fine roots; Sharp change to
B ₃	75 - 117	Medium brown sand; compact structure; dark brown organic staining, somewhat mottled with grey and yellow-orange colours; sharp change to
C	117+	Yellowish coarse sand, stratified, single grain structure.
Humus Iron Podzol		
A _{0F}	0 - 10 cm	(Countesswells Series formed on granite till, Calluna grass heath) Black to dark brown, partially decomposed mor; fibrous and resilient; matted by fine roots; sharp change to
A ₂	10 - 20	Grey, with small amount of dark brown humus staining, stony, loamy coarse sand; weakly coherent cloddy structure, held together by roots; sharp change to
B ₁	20	Thin iron pan sometimes present
B ₂	20 - 40	Yellow, with patches of dark brown humus staining; sandy loam; moderate stone content; soft and friable; weakly cloddy; roots frequent; sharp change into
B ₃	40 - 60	Pale yellow; stony, coarse loam; indurated; induration decreasing towards base; few roots penetrate; merging into
C	60+	Greyish yellow; stony, loamy, coarse sand till; moderately compact.

Appendix 3: Explanation of Acronyms in the Text

AEFD	Agriculture, Environment and Fisheries Department of the Scottish Office (equivalent to RAD before the creation of the Scottish Parliament in 1999)
BSE	Bovine Spongiform Encephalopathy
DAFS	Department of Agriculture and Fisheries of the Scottish Office (predecessor of AEFD, before the inclusion of Environment)
EC/EU	European Commission/Union
GDP	Gross Domestic Product
GM	Genetic Modification/Genetically-Modified
ICSC	International Crop Science Congress (3rd at Hamburg, August 2000)
m.c.	moisture content
ORS	Old Red Sandstone (freshwater deposits of the Devonian period)
RAD	Rural Affairs Department of the Scottish Executive
SAC	Scottish Agricultural College
WTO	World Trade Organisation

Appendix 4: The Economics of a Range of Cropping Enterprises: SAC Farm Management Handbook (Chadwick, 1999).

Values are Gross Margins, £ per hectare

Crop	Low input	Low input with area payment	Medium input	Medium input with area payment	High input	High input with area payment
W. wheat	305	545	485	725	667	907
W. barley	371	611	511	751	653	893
S. barley	217	457	357	597	499	739
W. oilseed rape	53	449	108	504	163	559
S. oilseed rape	86	482	141	537	196	592
S. linseed	-142	218	-70	290	-7	353
Protein peas	-14	282	98	394	211	507
Ware potatoes	1410	-	2071	-	2733	-
Seed potatoes	-	-	3064	-	-	-
Raspberries fresh	-	-	3046- 7257	-	-	-
Raspberries processed	-	-	-286-1704	-	-	-
Carrots	-	-	3001-4013	-	-	-
Leeks	-	-	4345	-	-	-
Calabrese	-	-	1515-3524	-	-	-
Timothy hay	-	-	545- 637	-	-	-

For full details of estimates, see Chadwick (1999)

