



Department of Agriculture, Food  
and Rural Development



# Investigations of Animal Health Problems at Askeaton, County Limerick

## **SOIL, HERBAGE, FEED & WATER**



**BÓRD SLÁINTE**  
AN MHÉAN-IARTHAIR



*Agriculture and Food Development Authority*

# Environmental Protection Agency

## Establishment

The Environmental Protection Agency Act, 1992, was enacted on 23 April, 1992, and under this legislation the Agency was formally established on 26 July, 1993.

## Responsibilities

The Agency has a wide range of statutory duties and powers under the Act. The main responsibilities of the Agency include the following:

- the licensing and regulation of large/complex industrial and other processes with significant polluting potential, on the basis of integrated pollution control (IPC) and the application of best available technologies for this purpose,
- the monitoring of environmental quality, including the establishment of databases to which the public will have access, and the publication of periodic reports on the state of the environment,
- advising public authorities in respect of environmental functions and assisting local authorities in the performance of their environmental protection functions,
- the promotion of environmentally sound practices through, for example, the encouragement of the use of environmental audits, the setting of environmental quality objectives and the issuing of codes of practice on matters affecting the environment;
- the promotion and co-ordination of environmental research;
- the licensing and regulation of all significant waste disposal and recovery activities, including landfills and the preparation and periodic updating of a national hazardous waste management plan for implementation by other bodies;
- implementing a system of permitting for the control of VOC emissions resulting from the storage of significant quantities of petrol at terminals;
- implementing and enforcing the GMO Regulations for the contained use and deliberate release of GMOs into the environment,

- preparation and implementation of a national hydrometric programme for the collection, analysis and publication of information on the levels, volumes and flows of water in rivers, lakes and groundwaters; and

- generally overseeing the performance by local authorities of their statutory environmental protection functions.

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The Agency is an independent public body. Its sponsor in Government is the Department of the Environment and Local Government. Independence is assured through the selection procedures for the Director General and Directors and the freedom, as provided in the legislation, to act on its own initiative. The assignment, under the legislation, of direct responsibility for a wide range of functions underpins this independence. Under the legislation, it is a specific offence to attempt to influence the Agency, or anyone acting on its behalf, in an improper manner.

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at Askeaton, Co. Limerick

**SOIL, HERBAGE, FEED AND WATER**

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## **Investigations of Animal Health Problems at Askeaton, Co. Limerick.**

### **Soil, Herbage, Feed and Water**

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## NOTE

This document is one of a five-volume report on the investigations of animal health problems in the Askeaton area of Co. Limerick, carried out in the period 1995 – 1998. The five volumes are as follows:

- Main Report
- Animal Health
- Soil, Herbage, Feed and Water
- Human Health
- Environmental Quality

The investigations were prompted by reports of severe animal health problems on two farms in the Askeaton area, which first came to notice in the early 1990s. In February 1995, following preliminary investigations by Limerick County Council, the Environmental Protection Agency was requested by the Minister of State at the Department of Agriculture, Food and Rural Development to co-ordinate a wider study of the situation. This was considered necessary, as there were local concerns that human health was also being affected in the area and that environmental pollution was involved.

Arrangements for the undertaking of the investigative work were put in place in late February 1995, this being assigned to the Veterinary Research Laboratory of the Department of Agriculture, Food and Rural Development (animal health), Teagasc (soils, herbage and related aspects), the Mid Western Health Board (human health) and the Environmental Protection Agency (environmental quality aspects). Subsidiary studies were carried out by Coillte and the Mid Western Health Board, respectively, on tree health and the levels of metals and other substances in vegetable produce.

Field measurements and observations took place between March 1995 and December 1998. Interim reports were published in December 1995, June 1996 and August 1998.

## **Acknowledgements**

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## TABLE OF CONTENTS

<b>CHAPTER 1 .....</b>	<b>1</b>
<b>1.1 THE ASKEATON PROBLEM FARMS, SOMERS AND RYAN.....</b>	<b>1</b>
1.1.1 <i>The Somers Farm .....</i>	<i>1</i>
1.1.2 <i>The Animal Health Problem .....</i>	<i>1</i>
1.1.3 <i>The Ryan Farm.....</i>	<i>3</i>
1.1.4 <i>The Animal Health Problem .....</i>	<i>3</i>
<b>1.2 METHODS .....</b>	<b>4</b>
<b>1.3 SYNOPSIS OF THE INVESTIGATION.....</b>	<b>5</b>
<b>CHAPTER 2 - SOIL SURVEY.....</b>	<b>6</b>
<b>2.1 INTRODUCTION.....</b>	<b>6</b>
<b>2.2 PARENT MATERIAL .....</b>	<b>6</b>
<b>2.3 SOIL SERIES.....</b>	<b>6</b>
<b>2.4 SOIL SUITABILITY .....</b>	<b>7</b>
<b>CHAPTER 3 - BOTANICAL SURVEY .....</b>	<b>13</b>
<b>3.1 INTRODUCTION.....</b>	<b>13</b>
<b>3.2 FARM OF LIAM SOMERS, ISSANE, ASKEATON .....</b>	<b>13</b>
3.2.1 <i>Silage Quality on the Somers Farm.....</i>	<i>18</i>
3.2.2 <i>Other Observations on the Somers Farm. ....</i>	<i>19</i>
<b>3.3 FARM OF JUSTIN RYAN, TOMDEELY NORTH, ASKEATON.....</b>	<b>20</b>
3.3.1 <i>Silage Quality on the Ryan Farm .....</i>	<i>22</i>
3.3.2 <i>Other Botanical Observations on the Ryan Farm .....</i>	<i>23</i>
<b>3.4 CONTROL FARM, ASKEATON .....</b>	<b>23</b>
3.4.1 <i>Silage Quality in the Control Farm .....</i>	<i>24</i>
<b>3.5 ADDITIONAL BOTANICAL INVESTIGATIONS 1995.....</b>	<b>24</b>
3.5.1 <i>Conifer Trees           25</i>	
3.5.2 <i>Broadleaved Trees.....</i>	<i>25</i>
3.5.3 <i>Detailed Assessment.....</i>	<i>25</i>
<b>CHAPTER 4 - SOIL ANALYTICAL RESULTS .....</b>	<b>26</b>
<b>4.1 INTRODUCTION - INVESTIGATION OF SOMERS, RYAN AND CONTROL FARMS - SOILS.....</b>	<b>26</b>
4.1.1 <i>Major And Trace Elements In Soils (and Plants) . . . . .</i>	<i>26</i>
4.1.2 <i>Ranges of Elements in Soils.....</i>	<i>27</i>
4.1.3 <i>Extractable Trace Elements in Soils.....</i>	<i>27</i>
4.1.4 <i>Effects Of Aerial Contamination On Soil And Herbage.....</i>	<i>29</i>
4.1.5 <i>Pollution of Herbage/Soil by Aerial Deposition.....</i>	<i>29</i>
4.1.6 <i>Geochemical Pollution .....</i>	<i>30</i>
4.1.7 <i>Mineral Deficiency.....</i>	<i>30</i>
<b>4.2 SOIL SAMPLING PROCEDURE .....</b>	<b>31</b>
<b>4.3 ANALYTICAL METHODS .....</b>	<b>31</b>
<b>4.4 MOISTURE, LOSS ON IGNITION, pH, LIME REQUIREMENT AND MACRONUTRIENTS ..</b>	<b>32</b>
<b>4.5 EXTRACTABLE SOIL MICRONUTRIENTS.....</b>	<b>33</b>
<b>4.6 TOTAL SOIL MICRONUTRIENTS.....</b>	<b>33</b>
<b>4.7 IRON, ALUMINIUM AND TITANIUM.....</b>	<b>35</b>
<b>4.8 HEAVY METAL CONCENTRATIONS IN SOIL.....</b>	<b>36</b>
<b>4.9 SELENIUM AND FLUORINE IN SOIL PROFILES .....</b>	<b>36</b>
<b>4.10 SUMMARY .....</b>	<b>37</b>
<b>4.11 RE-SAMPLING AND RE-ANALYSIS OF SOILS ON SOMERS FARM, NOVEMBER 1997.</b>	<b>38</b>
<b>4.12 SEDIMENT SAMPLES.....</b>	<b>38</b>
<b>CHAPTER 5 - HERBAGE ANALYTICAL RESULTS .....</b>	<b>42</b>
<b>5.1 INTRODUCTION.....</b>	<b>42</b>
5.1.1 <i>Ranges of Elements in Pastures.....</i>	<i>42</i>
5.1.2 <i>Seasonal Variation and Stage of Maturity.....</i>	<i>42</i>
5.1.3 <i>Soil Contamination of Herbage.....</i>	<i>42</i>
5.1.4 <i>Toxicity.....</i>	<i>43</i>
<b>5.2 SAMPLING AND ANALYSIS .....</b>	<b>43</b>
<b>5.3 HERBAGE - MACRONUTRIENTS.....</b>	<b>43</b>

5.4	HERBAGE - ESSENTIAL MICRONUTRIENTS.....	45
5.5	HERBAGE - HEAVY METALS .....	46
5.6	SUMMARY .....	46
5.7	MISCELLANEOUS BIOLOGICAL SAMPLES.....	47
5.8	SULPHUR - INTRODUCTION .....	47
5.8.1	<i>Factors Influencing Herbage Sulphur</i> .....	47
5.8.2	<i>Normal Herbage Sulphur Levels</i> .....	48
5.8.3	<i>Sulphur Analytical Aspects</i> .....	48
5.9	SULPHUR, COPPER, MOLYBDENUM .....	50
5.10	MONITORING OF HERBAGE FROM RYAN AND SOMERS FARMS.....	51
5.11	OTHER MONITORING.....	54
CHAPTER 6 - WATER, MINERAL MIX, CONCENTRATE AND FORAGE ANALYSIS .....		59
6	WATER .....	59
6.1	TAP WATER.....	59
6.2	STREAM WATER AND DRAIN .....	60
6.3	TROUGH WATER.....	60
6.4	CONCENTRATES AND MINERAL MIXTURES .....	61
6.4.1	<i>Results</i> .....	61
6.5	FODDER.....	61
6.5.1	<i>Sampling</i> .....	61
6.5.2	<i>Fodder 1995. Presentation And Quality Analysis 1995</i> .....	61
6.5.3	<i>Silage 1995 - Mineral Analysis</i> .....	62
6.5.4	<i>Hay 1995 - Mineral Analysis</i> .....	62
6.5.5	<i>Silage 1997</i> .....	62
CHAPTER 7 - LONGITUDINAL STUDY.....		63
7.1	SOIL AND HERBAGE.....	63
7.2	SILAGE ANALYSIS .....	63
CHAPTER 8 - RETROSPLECTIVE SURVEY .....		64
8.1	INTRODUCTION.....	64
8.2	SAMPLING AND ANALYSIS .....	64
8.3	SOIL RESULTS.....	66
8.4	SOIL RESULTS - NOVEMBER 1997 .....	66
8.5	HERBAGE RESULTS - JULY 1997.....	67
8.6	HERBAGE RESULTS - NOVEMBER 1997 .....	67
8.7	SILAGE RESULTS .....	68
8.8	ADDITIONAL ANALYSES .....	68
8.9	FOLLOW UP INVESTIGATION OF 3 INSTANCES OF SEVERE GEOCHEMICAL POLLUTION .....	68
8.9.1	<i>Selenium</i> .....	68
8.9.2	<i>Zinc and Lead</i> .....	68
8.9.4	<i>Metals in Potato Fohage</i> .....	69
8.9.5	<i>Summary</i> .....	69
CHAPTER 9 - ADDITIONAL INVESTIGATIONS .....		70
9.1	SOILS.....	70
9.2	INSPECTION OF HEDGEROWS AND GRASSLAND AT ASKEATON .....	70
9.2.1	<i>Farm RS 05</i> .....	70
9.2.2	<i>Farm RS 28</i> .....	71
9.2.3	<i>Additional Farm</i> .....	71
9.2.4	<i>Farm RS 17</i> .....	71
9.2.5	<i>Farm of Liam Somers, Askeaton</i> .....	71
9.2.6	<i>Farm RS 24 Askeaton</i> .....	71
9.2.7	<i>Trees and shrubs at Johnstown, Tipperary and east Co. Limerick</i> .....	71
9.2.8	<i>Comment and Conclusion</i> .....	72
REFERENCES.....		73
APPENDICES .....		76



# CHAPTER 1

## 1.1 THE ASKEATON PROBLEM FARMS, SOMERS AND RYAN

The following is a brief description and case history of the Somers and Ryan farms.

### 1.1.1 The Somers Farm

Liam and Mary Somers operate a typical County Limerick dairy farm. The farm is in one compact unit and the western edge borders the public road from Askeaton to Ballysteen. The farmyard and new farmhouse are at the northwest corner of the farm. A private farm road running north south gives access to the various paddocks.

The farm is all at an elevation of between 20 and 30 m. There is a small hill of 30 m height in the south west of the farm and it is topped by a pre-historic ringfort. There is flat, open country as far as the Shannon to the west of this hillock and indeed of the farm generally. Aside from the immediate vicinity of the hillock the farm is generally flattish to gently rolling.

Mr. Somers inherited the farm from his mother in 1966. The area of the farm was 19.9 ha (approx. 18.7 ha adjusted) which carried 20 dairy cows and followers. The farm was run in the traditional manner where the cows were housed in a tie up byre, fed on hay and milked using a bucket type milking machine. Cow numbers increased gradually to reach a herd size of 30 producing approximately 127t (28,000 gallons) of milk by the early eighties. The introduction of milk quotas in 1983 restricted milk production to this level.

Efficient and effective farm practices were adopted during the period of herd expansion. Lime and fertiliser use increased with an associated cost of £ 143 ha<sup>-1</sup> in 1986. This reflects a high usage compared with similarly stocked farms. Fertiliser use for grass production is in line with Teagasc recommendations for the current level of stocking. Average stocking rate was approximately 2.02 livestock units (LU) ha<sup>-1</sup> in 1986. The stocking rate gradually increased to approximately 2.2 LU ha<sup>-1</sup> by 1993. This was due to an increase in the number of non-dairy livestock. The animal health problem made normal stock sales difficult.

A central farm roadway with paddocks, piped water and mains electric fencing allowed stock to be grazed on a rotational basis. The tie up cow byre and haybarn were replaced by a 32 cow cubicle shed, roofed silo, exercise yard and dungstead. Silage rather than hay became the primary source of winter feed.

In the late eighties an additional 4 ha were acquired bringing the farm size to 23.9 ha. Extra calves were reared and kept on the farm until they were 12 to 18 months old. No animals were bought onto the farm at any time during the past 30 years, with the exception of a bull.

### 1.1.2 The Animal Health Problem

In 1986, there were 33 cows at the start of the year with an average of 30 milking. Cow numbers on the farm remained between 32 and 35 up to 1994 (Table 1.1). Approximately 122 t (26,903 gallons) of milk was sold during that year (Table 1.1). Milk sale declined progressively each year to a low of 62.4 t (13,719 gallons) in 1992.

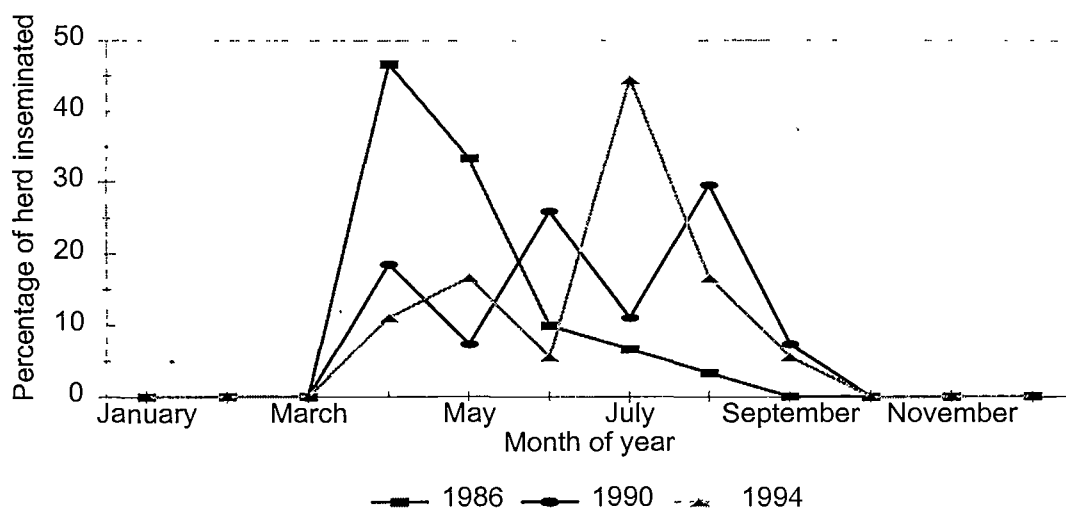
Calf and cow deaths also increased substantially and peaked in 1993 when 7 cows, 16 calves and 4 other animals died (Table 1.1). Most calvings were normal, with few abortions or still-births. Calf deaths occurred soon after birth. It proved particularly difficult to get cows in-calf, particularly during the 1990

to 1994 period. This difficulty resulted in a change in the herd calving pattern from the preferred spring calving to all year round calving. The trend is reflected in the percentage of the herd inseminated each month (Fig 1).

**Table 1.1:** Temporal trends in area stock numbers, mortality, milk sales, and fertiliser purchased on the Somers farm

	1986	1988	1990	1991	1992	1993	1994
Adjusted Area Farmed (ha)	18.8	18.8	22.86	22.86	22.86	22.86	22.86
Cows in Herd at Start of Year	33	32	32	34	35	32	30
Live Births	30	32	32	25	25	32	30
Stillbirths/Abortions	-	-	-	2	-	-	-
Cows/Heifers not in Calf	3	4	1	9	10	7	6
Stock Bull	-	-	1	1	1	-	-
Other Livestock (L.U.)	5	6.5	15.0	12.0	12.0	20.0	20.0
Est. Stocking Rate (L.U. ha <sup>-1</sup> )	2.02	2.04	2.10	2.05	2.10	2.27	2.19
Milk Sales (t)	122.3	103.2	79.6	85.1	62.4	65.1	80.4
<u>Mortality</u> Calves	6	7	4	8	9	16	6
Cows	-	-	2	3	4	7	2
Others	-	-	-	-	-	4	1
Fertiliser Purchase (£)	2713	2387	2529	2740	2672	2001	2744

(These figures were extracted from Co-op, milk statements, tax profiles and annual livestock charts recorded by Liam Somers)



**Figure 1:** Temporal trends in herd inseminations 1986, 1990 and 1994 on the Somers farm.

### 1.1.3 The Ryan Farm

The Ryan's operated a 34 ha dairy farm near Askeaton, County Limerick. The farm was in one compact unit on both sides of a public road from Askeaton to Massy's Quay. It had a long border on the east with the tidal estuary of the River Deel, a tributary of the Shannon. The farmyard and new farmhouse were at the extreme southern end of the farm. The farm was all at an elevation of from 20 to 40 m.

Originally the farm was in two separate parts. A Land Commission settlement (land swap) in the early seventies made the farm a single unit. A further 14 ha was purchased in 1972, financed by the sale of a site for development purposes. At this time the farming system was mixed. By the mid seventies it was an all grassland farm and had changed over completely to dairying.

The herd consisted of approximately 60 cows and was maintained at this level until 1995. The calves were generally fed fresh milk and sold at 1 to 2 months of age. Replacement heifers were purchased. The system developed was an intensive, low cost one. A New Zealand type herringbone milking parlour was erected in 1974. It was one of the first of this popular system in the county.

The milk quota for the farm was 204.5 t (45,000 gallons). This is a respectable milk output considering that whole milk was fed to calves and the low input character of the system. The cows were calved predominantly between January and March. In 1988/89 a bull was introduced instead of artificial insemination and the herd calving date was delayed further into spring.

Hay was the main winter forage until 1982. Subsequently baled silage was used. Mr. Ryan was the first farmer in the area to buy a round baler to make baled silage. Up to 1988, the cows received no meal supplementation while on grass, but summer meal feeding was then practiced. During the farm development period, or at no period since, was any grant aid been sought or received by the Ryans.

The stocking rate was consistently in the region of 2.1 LU ha<sup>-1</sup> and nitrogen use on pasture ground has been in the region of 625 kg of Calcium Ammonium Nitrate ha<sup>-1</sup> (172 kg nitrogen ha<sup>-1</sup>) which is more than adequate for the stocking rate.

**Table 1.2:** Temporal trends in cow numbers, milk sales and mortality on the Ryan farm

	1985	1991	1993	1994	1995
Cow Nos	60/63	60	60	60/62	60
Milk Sales (t)	241			164	
<u>Mortality</u>					
Calves		7	9	-	-
Cows		3	3	14	18
Others		-		(4)	2

### 1.1.4 The Animal Health Problem

Information given by Justin Ryan indicated that milk sales peaked around 1986 (Table 1.2). Approximately, 241t (53,000 gallons) was sold in that year. Milk sales fell consistently each year to a low of 164 t (36,000gallons) in 1994. During this period, Mr. Ryan also reports a major increase in abortion/stillbirths and deaths (Table 1.2). He reported that four of seven in-calf heifers purchased aborted and two of them subsequently died. A further one died following calving. In 1994, 14 cows and some weanlings died. During 1995, 18 cows and two other animals died.

## 1.2 METHODS

This field investigation was conducted to obtain evidence of previous inputs to soil, herbage and water that may have contributed to the animal health problems on farms in the Askeaton area. Since soil acts as a long term reservoir, soil analysis can provide evidence of historical inputs. It also provides an indication of possible plant nutritional factors (deficiencies/toxicities) that may contribute to animal health problems. Herbage and conserved fodder act as a short term reservoir thereby providing evidence of more recent inputs. It also acts as a direct indicator for animal dietary/nutritional problems.

The objective of the investigation was to gather as much evidence as possible on the quality and diversity of the soils, herbage, fodder, concentrates (animal feed) and water on the two farms which by 1995 had reported animal health problems with a view to attributing causes for the problems.

Initially, a number of assignments were identified to achieve the objective.

1. To conduct a survey of soil types and a botanical survey of pasture species.
2. To identify (a) any abnormally high levels of heavy metals and (b) possible deficiencies/excesses of trace elements and other elements important to animal health, in soils and herbage.
3. To identify any abnormal element levels in hay, silage, feed concentrates, mineral mixtures, sediments, surface water and tap water.
4. To evaluate the possibility of contamination of soils and herbage by a variety of inorganic and some persistent organic pollutants.

A sampling programme of soil, silage, concentrates, feed supplements, vegetation and water sources was conducted by Teagasc on the following three farms. The first was the dairy farm of Mr L. Somers who had animal health problems in the early nineties. The second was the dairy farm of Mr J. Ryan who reported the loss of 18 cows in the spring of 1995. For comparative purposes, in the event of a serious compositional anomaly being found on one or both of the problem farms, a third farm was included in the investigation. The third farm, hereafter known as the Control farm, was that of Mr. J. O'Brien, which is in the area of the two problem farms and had not reported any abnormal animal health problems at the time. The Control farm is also a dairy farm. The above investigations were conducted while the animal death problem was still apparently ongoing on the Somers Farm and was most active on the Ryan Farm.

A herbage monitoring program was conducted on the farms of Mr. Somers and Mr. Ryan between November 1995 and February 1998. Samples were obtained at *ca* three weekly intervals and were analysed for sulphur, selenium, molybdenum and nitrogen.

Subsequently, in July and again in November 1997, soil and herbage was collected from farms in the Askeaton area that were participating in the retrospective and longitudinal studies. From each farm, a soil sample from under both grazing and silage ground was taken together with herbage. In this way about 45 samples of both soil and herbage was obtained from 23 farms. A sample of conserved fodder (predominantly silage) was also obtained from each farm.

Analyses were also conducted on additional soil, herbage and silage samples to assist in the overall investigation.

### 1.3 SYNOPSIS OF THE INVESTIGATION

The investigation was structured to include the following:

- 1) In relation to Index Farms, Somers, Ryans and a third farm to serve as a control in the same area:
  - a) Soil survey, classification and evaluation of production potential (1983).
  - b) Botanical evaluation of herbage and of vegetation (1995-1999).
  - c) Soil sampling and chemical analysis for a wide range of inorganic components (1995-1998).
  - d) Herbage sampling and chemical analysis (1995-1998).
  - e) Water, fodder and concentrate analysis (1995).
- 2) In relation to longitudinal study : analysis for soil, herbage and fodder (1997-1998).
- 3) In relation to retrospective study : analysis of soil, herbage and fodder (1997-1998).

## **CHAPTER 2**

### **SOIL SURVEY**

#### **2.1 INTRODUCTION**

A soil survey of the three farms was carried out on March 21, 22 and 23, 1995. The purpose of the survey was to identify the soil types and assess the land quality on the farms. Approximately 70 auger borings were made up to a depth of 1 m. This forms a detailed survey. Profile development, parent material, drainage and texture are the main characteristics used in the classification. The soil series definitions established by the National Soil Survey were used to name the soils. The distribution of the soil series on each farm is shown on the accompanying maps (Figs 2, 3 and 4).

#### **2.2 PARENT MATERIAL**

The three farms overlie Carboniferous limestone bedrock. Lower Carboniferous earthy limestone underlies the Somers farm. Unbedded reef limestones which reflect clear water marine sedimentation, underlie the Control and Ryan farms (Geological Survey of Ireland, 1969; O'Meara, 1966). Till comprising mainly carboniferous limestone covers the Somers and Control farms and the western part of the Ryan farm (Synge, 1966). The eastern part of the Ryan farm consists of rock waste or thin drift cover.

The three farms occur within the Fedamore stage of the Weichsel glaciation (Midlandian advance). The ice came from the North (N) or North-East (N.E.). This indicates that Black Shales which occur to the West in Limerick and to the North West in Clare are unlikely constituents of the till. A section examined at a site beside the Somers farm consisted of calcareous gravely till composed predominantly of limestone with very small amounts of sandstone and shale.

Alluvium occurs in a small basin (3.8 ha) on the Somers farm and in a small (1.5 ha) narrow strip along the western margin of the Control farm. These deposits occur in small catchments that lie within the limestone region and are derived from the local limestone till.

#### **2.3 SOIL SERIES**

All the soils found on the farms have been classified previously by the National Soil Survey. A key to the series showing their differentiating characteristics is presented in Table 2.1. These soils are widespread in the central plain (Finch and Ryan, 1966; Finch, 1977; Conry, 1987) where naturally occurring elevated mineral values (with the exception of molybdenum) are not associated with them.

The eight series form seven map units. The Elton series occurs as inclusions within the Patrickswell series and was not delineated separately. Table 2.2 shows the distribution of the soils on the farms. Free draining soils predominate on all farms ranging from 0.75 on the Somers farm to 1.0 on the Control farm. The remainder consists of wet land on the Somers farm and rocky land on the Ryan farm.

At the time of the survey surface poaching was extensive on wet and free draining land on the Somers farm and occurred to a lesser extent on the Ryan farm. On the Control farm there was very little surface poaching. Evidence of anaerobic conditions was found in the top-soil (A horizons) at nearly every site. This reflects structural damage caused by animal or machine traffic.

**Table 2.1:** Soil classification

Series	Symbol	Characteristics
Patrickswell	Pw	Grey Brown Podzolic/Brown Earth derived from calcareous gravely till, loam, well drained solum 400-850 mm
Elton	-	Similar to Patrickswell. Solum >850 mm
Kinvarra	Kv	Brown Earth derived from calcareous gravely till/or weathered limestone, loam. Well drained. Solum < 400 mm.
Rocky land	R	Kinvarra soils with abundant outcrops of limestone bedrock.
Mylerstown	Mt	Gley derived from calcareous gravely till, loam, imperfect to poorly drained. Solum < 850 mm.
Ballyshear	Bs	Peaty gley derived from calcareous gravely till, loam, poorly drained.
Coolalough	Ca	Peaty gley derived from calcareous alluvium silt loam, poor to very poorly drained, high water table.
Camoge	Cm	Gley derived from river alluvium, silt loam, poorly drained.

**Table 2.2:** Distribution of soils on the Somers, Ryan and Control farms

Soil Series	Somers	Ryan (ha)	Control	Somers	Ryan (proportion)	Control
Patrickswell	18.0	16.8	21.6	0.753	0.500	1.0
Kinvarra	0.0	8.7	0.0	0.000	0.258	0.0
Camoge	0.0	1.5	0.0	0.000	0.045	0.0
Mylerstown	2.1	0.0	0.0	0.088	0.000	0.0
Coolalough/Ballyshear	2.8	0.0	0.0	0.117	0.000	0.0
Rocky Land	0.0	6.6	0.0	0.000	0.197	0.0
Coolalough	1.0	0.0	0.0	0.042	0.000	0.0
	23.9	33.6	21.6	1.000	1.000	1.0

## 2.4 SOIL SUITABILITY

Soil suitability is an evaluation of the degree of suitability of each soil unit for a given use or set of uses. It is an interpretative classification that involves estimates of the relative degree of limitation. In this case the relevant land use type is confined to grassland. The limitations on the farms are wetness (w), drought (d) and rockiness (r). The soils are grouped into five classes designated A (good), B, C, D, E (very poor) for grassland. Productivity is the dominant criterion in the suitability for grassland and the suitability classes parallel the grazing capacity classes. Table 2.3 shows the distribution of the suitability classes on the farms. The Control farm consists entirely of Class A land. The Somers farm is predominately Class A land (0.78). Wetness is the principal limitation on the Somers farm. The wet Coolalough unit is assigned to class Ew and comprises 0.04 of the farm. Class A land occupies 0.50 of Ryan farm. The

Kinvarra soils on the Ryan farm have drought limitations and are assigned to class Bd. Rockiness is the major limitation on the Ryan farm; rocky land occupies 0.20 of the farm.

**Table 2.3:** Distribution of suitability classes by farm

Suitability Class	Farm					
	Somers	Ryan (ha)	Control	Somers	Ryan (proportion)	Control
A	18.0	16.8	21.6	0.753	0.500	1.0
Bd*	0.0	8.7	0.0	0.000	0.258	0.0
Cw	2.1	1.5	0.0	0.088	0.045	0.0
Dw	2.8	0.0	0.0	0.117	0.000	0.0
Er	0.0	6.6	0.0	0.000	0.197	0.0
Ew	1.0	0.0	0.0	0.042	0.000	0.0

\*d = drought; w = wetness; r = rockiness limitations

A comparison of the stocking rate capacity (proportion of farm that is assigned to each soil series multiplied by the stocking rate of the series) for the three farms is shown in Table 2.4. The stocking rate assigned to the soils are values published previously for these soils (Lee and Diamond, 1972).

**Table 2.4:** Estimated relative stocking rate capacity (LU ha<sup>-1</sup>) on Somers, Ryan and Control farms

Soil Series	Stocking Rate*	Somers	Ryan	Control
Pw	2.20	1.66	1.10	2.20
Kv	2.00	0.00	0.52	0.00
Cm	1.73	0.00	0.08	0.00
Mt	1.73	0.15	0.00	0.00
Ca/Bs	1.48	0.17	0.00	0.00
R	1.10	0.00	0.22	0.00
Ca	1.10	0.05	0.00	0.00
Total (LU/ha)		2.03	1.91	2.20
Ratio (Control =1)		0.92	0.87	1.00

\*Assigned to each soil series

This indicates that for similar inputs and feed supply the ratio of the stocking rate on the Somers and the Ryans farm compared to the Control farm is 0.92 and 0.87, respectively. The least confidence is placed in the estimates for the wet and rocky land (Classes D, E). In the hypothetical case where Class D & E land is assumed not to contribute to the feed supply the ratios would fall to 0.84 (Somers) and 0.77 (Ryan). Thus, to provide an equivalent feed supply, the required stocking rate on the Somers farm is calculated to be 0.08 to 0.18 less than on the Control farm. The corresponding estimates for the Ryan farm are 0.13 to 0.23.



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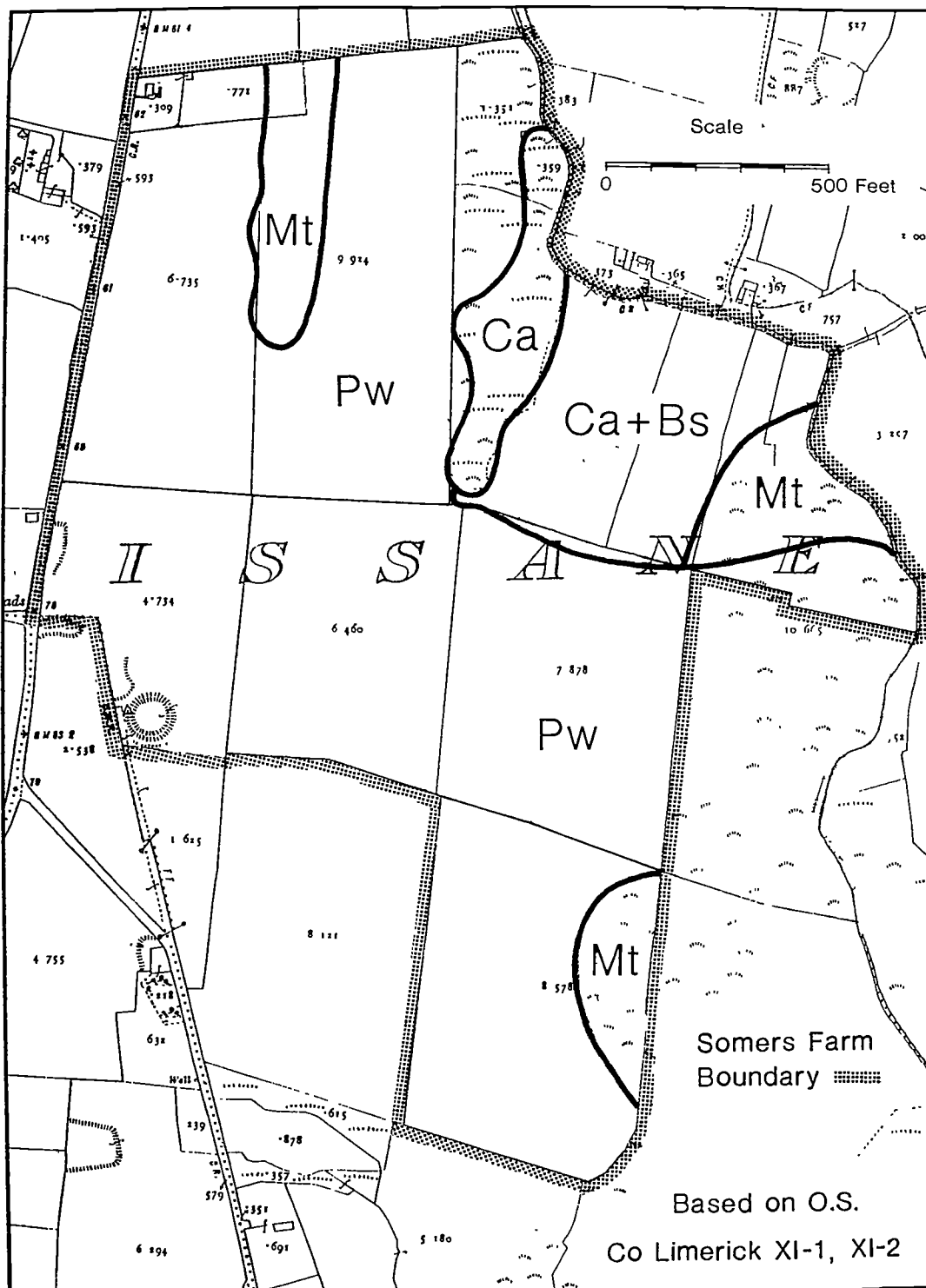


Figure 2: Distribution of the soil series in the Somers farm.

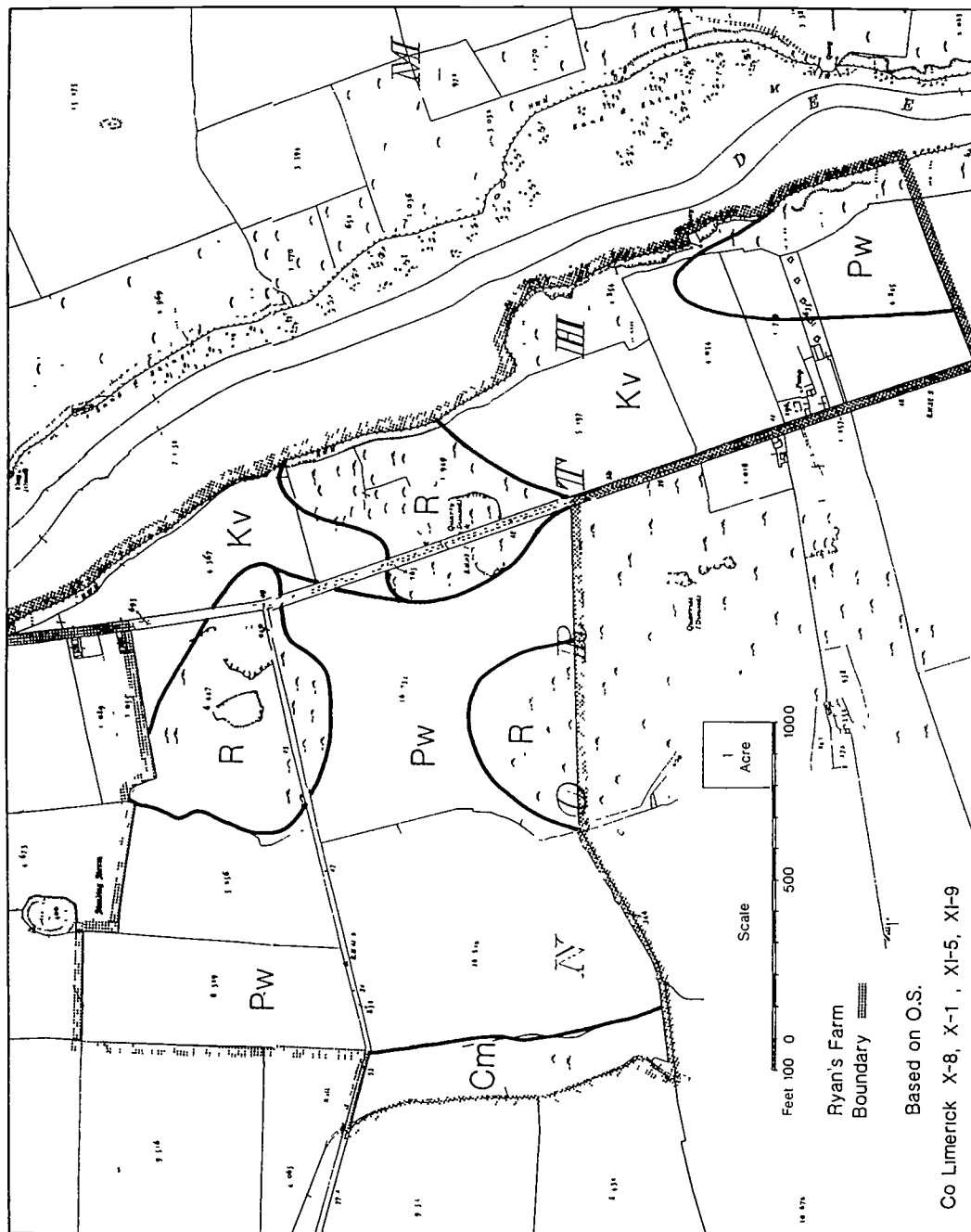
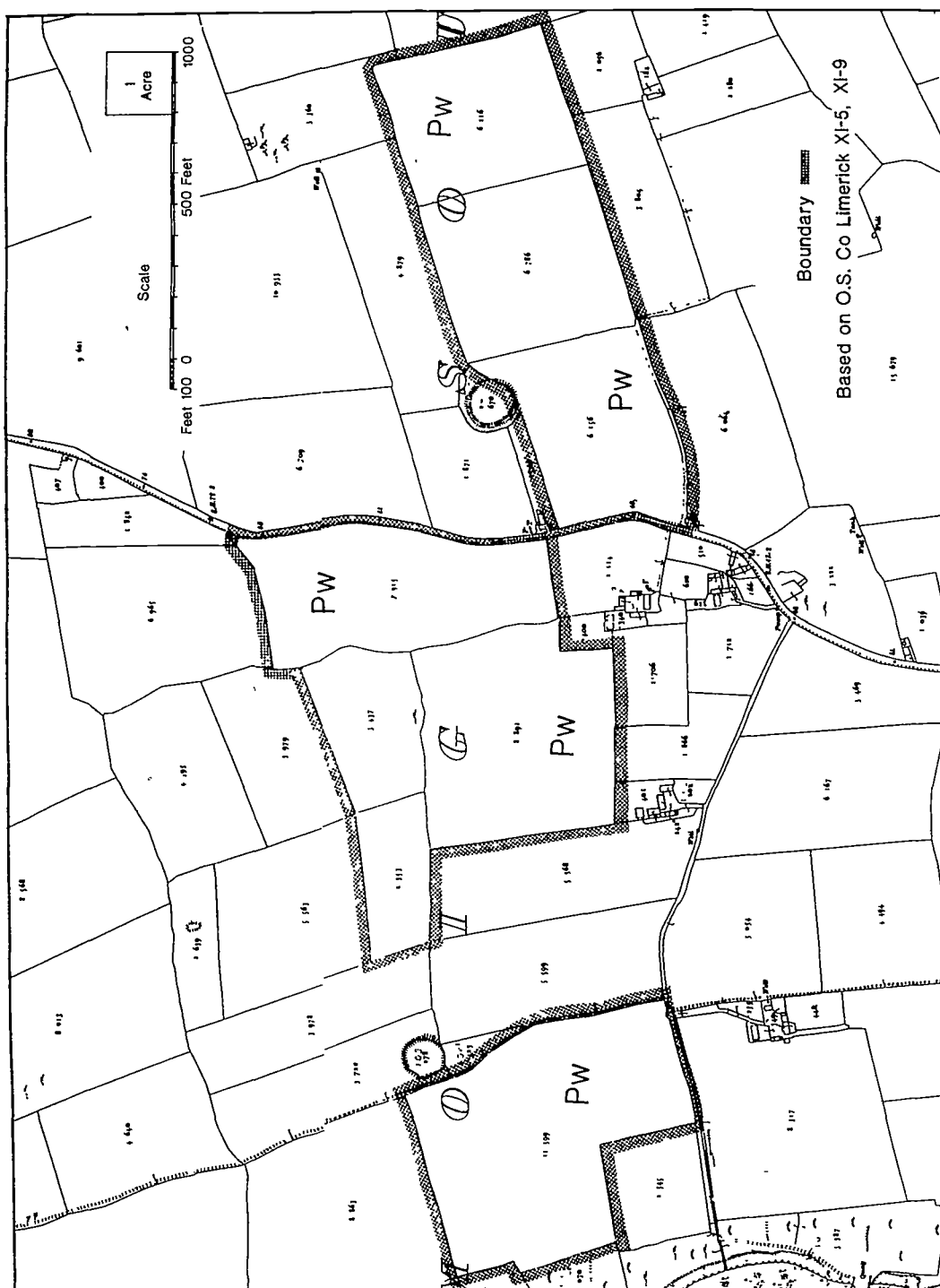


Fig. 3: Distribution of the soil series in the Ryan farm.



## CHAPTER 3

### BOTANICAL SURVEY

#### 3.1 INTRODUCTION

All farms were visited initially on March 22 and again on May 15, 1995. On both occasions observations were made in the field on the botanical composition of the pastures. The paddock numbers on each farm are identified in Figs 5, 6 and 7. In addition, herbage samples, taken between May 9 and 11 for chemical analysis, were examined in detail at the laboratory for species composition.

#### 3.2 FARM OF LIAM SOMERS, ISSANE, ASKEATON

The farm appears to have been originally in nine fields. A few field boundaries have been removed entirely, a farm road has been built and some of the bigger fields have been sub-divided into paddocks with electric fences. The farm is all in grass. A few paddocks, notably No. 3 and 3A have been reseeded in the last ten years. The farm had been heavily grazed. Some young cattle were outwintered on silage in the end of Paddock No. 1 on the highest part of the farm.

There were clear signs of grazing of hedgerows and hedge banks on the farm. The ground was often totally poached in a narrow strip running along the base of a hedgerow or field boundary. Grasses, herbs, ivy and briars around the edges of paddock No. 1, 6, 11, 19, 20 and 21 showed signs of having been grazed in recent months. The surface of most paddocks was damaged by poaching to varying degrees in March (Table 3.1).

**Table 3.1:** Degree of poaching observed in paddocks in March on the Somers Farm

Paddock No.	Degree of Poaching
1	Severe
3	Moderate to severe
6/7	Moderate
11	Moderate to severe
13/14/15	Severe
16	Slight
17/18/19	Moderate to severe
20/21	Moderate
22	Moderate
23	Slight
24/25/26	Slight

A botanical examination of the farm was carried out on March 22 and again on May 15. The cover formed by perennial ryegrass in each paddock on these two dates is summarised in Table 3.2.

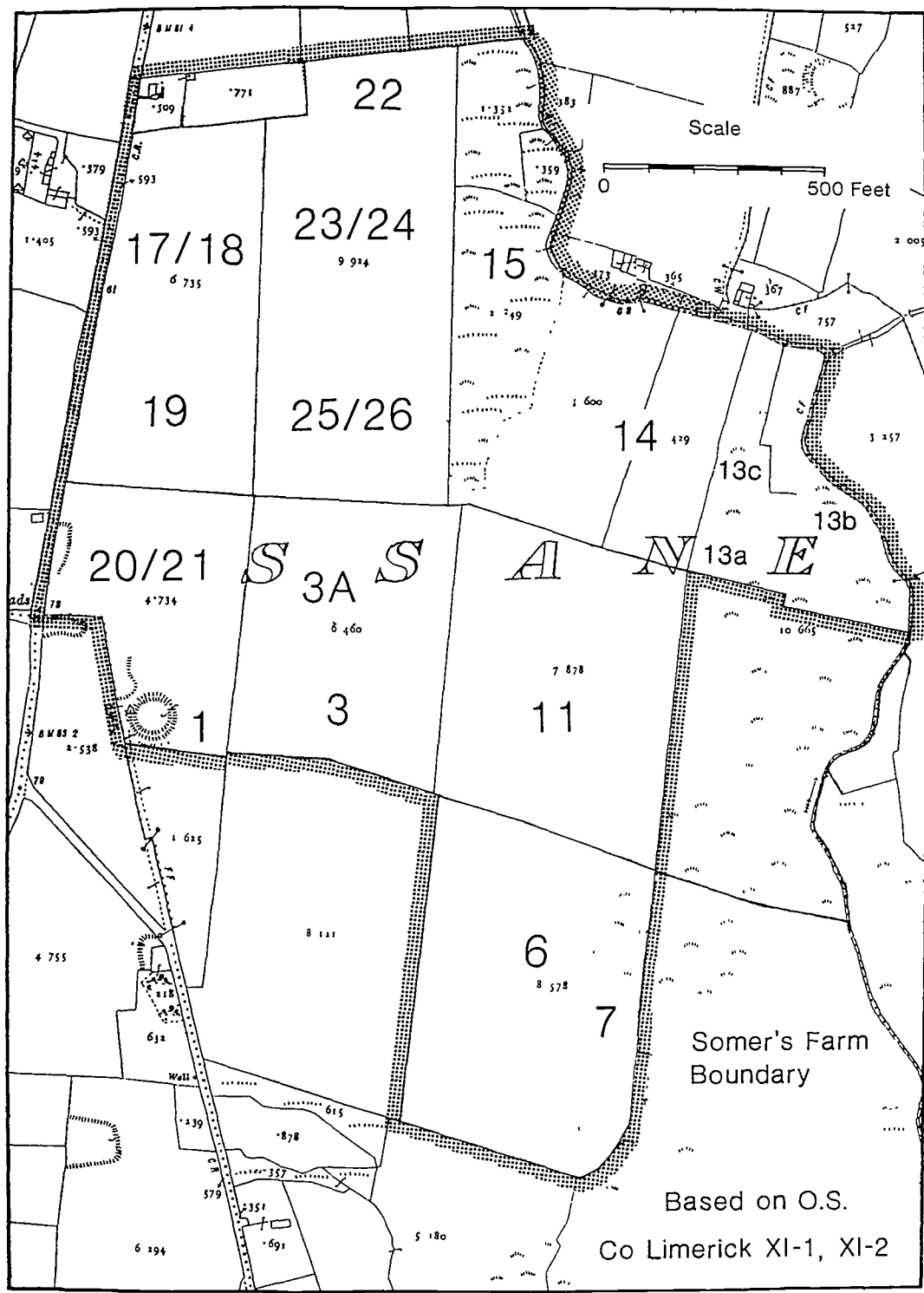


Fig. 5: Paddock numbers on the Somers farm.

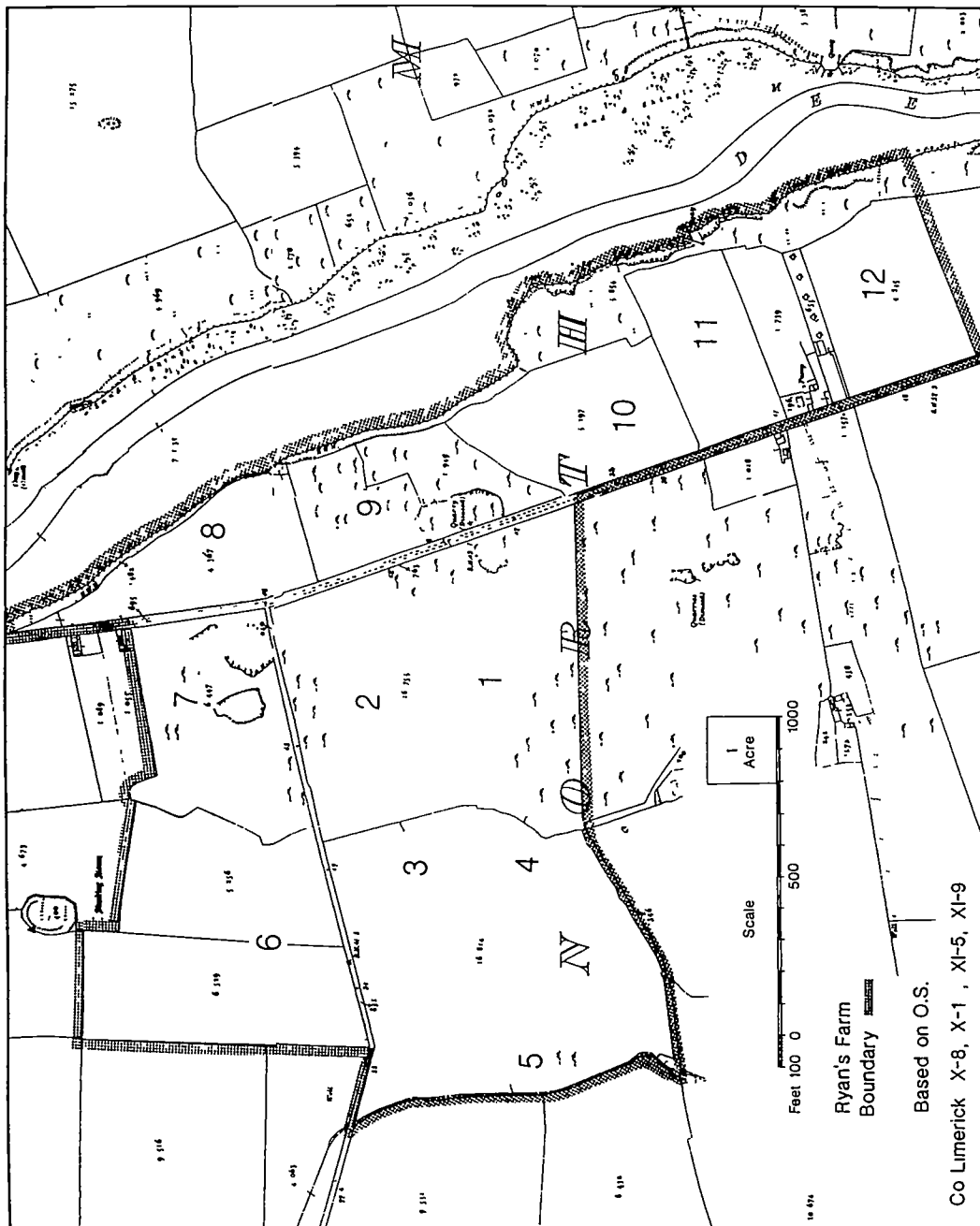


Fig. 6: Paddock numbers on the Ryan farm.

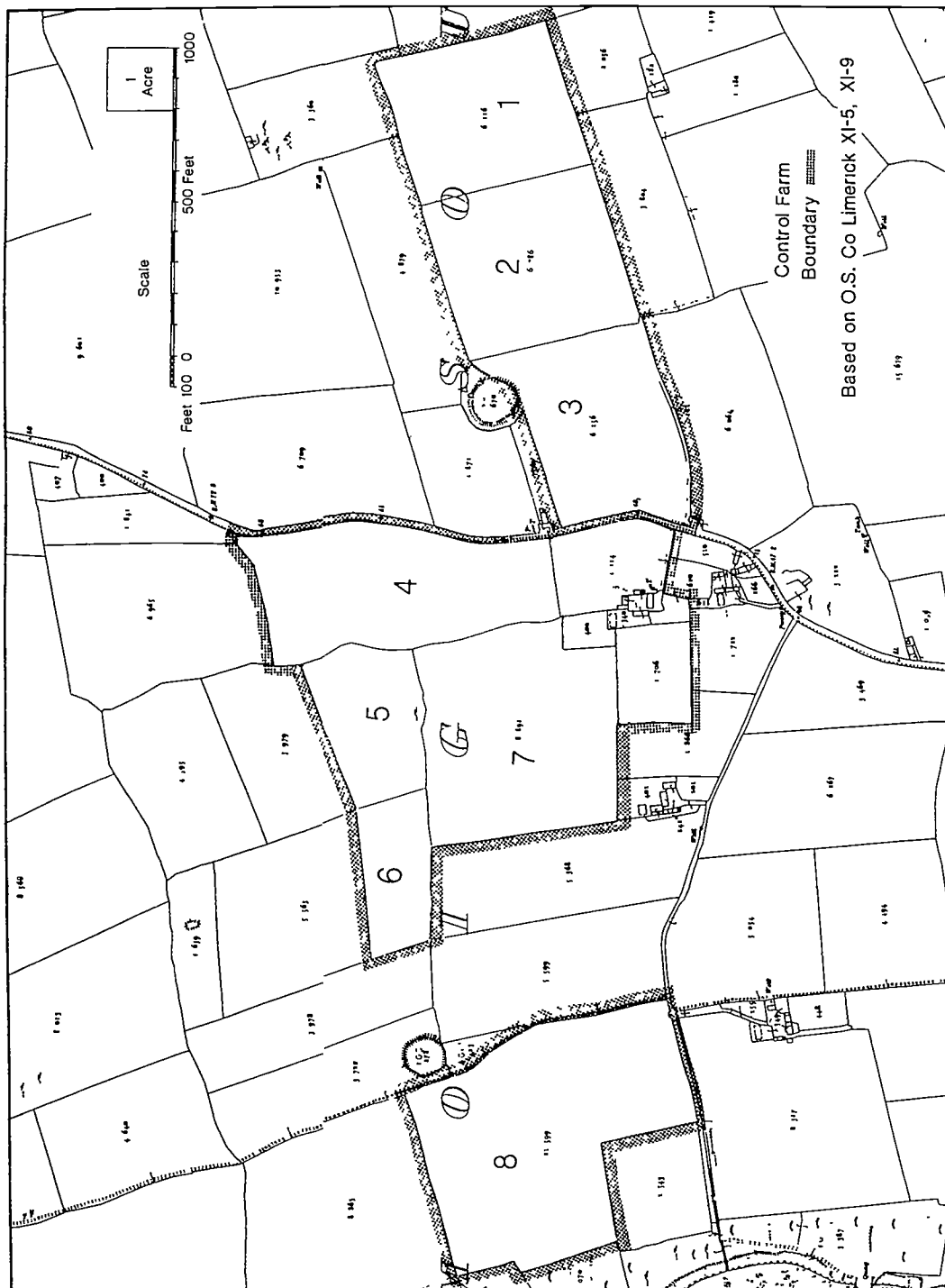


Fig. 7: Paddock numbers on the Control farm.



**Table 3.2:** Percentage perennial ryegrass cover on each paddock in March and May 1995 on the Somers farm

Paddock No.	March 22	May 15
1	(severely poached)	0.50
3	0.20	0.80
6/7	0.20	0.50
11	0.15	0.60
13/14/15	0.10	0.40
15	0.30	0.30
17/18/19	0.20	0.35
20/21	0.40	0.40
22	0.30	0.80
23/24	0.40	0.40
25/26	0.50	0.50
Mean ryegrass cover	0.28	0.50

There was a mean cover of ryegrass (perennial and Italian combined) in late March of 0.28. This had risen to 0.50 by the middle of May. The cover of ryegrass varied from 0.36 to 0.87 on individual farms in a detailed survey of ten intensive dairy farms in 1982 in the Cork/Waterford area. The mean for all ten farms was 0.62. A high ryegrass content in the swards is generally associated with successful dairy farming in Western Europe.

A separate herbage sampling of the Somers farm was conducted for chemical analysis in May (5.2). The botanical composition of these fresh herbage samples was determined at Johnstown Castle. This also gave the contribution to the yield of the different grass species present (Table 3.3). There was a mean contribution to the yield by the ryegrass of 0.42. This figure is close to that of 0.50 obtained by qualitative examination of the paddocks (Table 3.2).

When the farm was first visited on March 21 it had all been severely grazed in previous months. The mean grass height on all paddocks was 50 mm or less. There was a dramatic improvement observed when visited again on May 15. The paddocks which were closed for silage had a dense, lush, grass growth about 450 mm tall. Even the paddocks which were being grazed were showing good grass recovery. Most paddocks had 0.40 or more of ryegrass. The only area still showing poor growth was the wet area in the north east of the farm. It had a very low ryegrass content and was dominated instead by slow-growing marsh species.

The detailed botanical composition is given in Table 3.3. All of the normal grassland paddocks are of the *Lolio-Cynosuretum*<sup>1</sup> type. This would account for about three quarters of the farm. The remaining quarter consists of the Marsh area and of one field in fallow.

There was virtually no sign of poisonous weeds on the farm. Ragwort (*Senecio jacobea*) was virtually absent.

<sup>1</sup>In this International phytosociological system of classification units are defined more on overall botanical composition rather than on dominance of particular species.

**Table 3.3:** Botanical composition and the contribution of the different species to the yield

Species	Ryan	Somers	Control
<i>Lolium spp.</i>	0.263	0.422	0.607
<i>Agrostis spp.</i>	0.252	0.059	0.145
<i>Holcus</i>	0.158	0.010	0.045
<i>Poa spp</i>	0.182	0.344	0.099
<i>Alopecurus</i>	0.002	0.002	0.005
<i>Trifolium repens</i>	0.004	0.010	0.005
<i>Agropyron</i>	0.000	0.001	0.000
<i>Anthoxantum</i>	0.003	0.003	0.001
<i>Bellis</i>	0.002	0.004	0.000
<i>Bromus mollis</i>	0.001	0.000	0.000
<i>Cardamine</i>	0.000	0.001	0.000
<i>Carex demissa</i>	0.000	0.001	0.000
<i>Cerastium</i>	0.000	0.001	0.003
<i>D. glomerata</i>	0.001	0.001	0.002
<i>Equisetum</i>	0.000	0.001	0.000
<i>F. rubra</i>	0.005	0.001	0.000
<i>J. articulatus</i>	0.000	0.006	0.000
<i>Mentha</i>	0.000	0.001	0.000
<i>Plantago lanceol</i>	0.000	0.001	0.000
<i>Rannunculus acri</i>	0.000	0.001	0.000
<i>Rannunculus fla</i>	0.000	0.001	0.000
<i>Rannunculus rep.</i>	0.001	0.008	0.002
<i>Rumex conglom</i>	0.000	0.001	0.000
<i>Rumex obtusifoli</i>	0.001	0.001	0.000
<i>Senecio</i>	0.002	0.000	0.000
<i>Stellaria media</i>	0.000	0.000	0.002
<i>Taraxacum</i>	0.001	0.003	0.000
<i>Veronica agrestis</i>	0.000	0.000	0.001
<i>Others</i>	0.125	0.119	0.087

### 3.2.1 Silage Quality on the Somers Farm

Three silage samples were taken on March 21 results and sent to Teagasc Grange for analysis. The results are summarised in Table 3.4. Analysis of these and other silages, collected on this occasion, are given more fully in Appendix 17 and 18.

**Table 3.4:** Feed quality analysis results of three silage samples taken from the Somers farm

Test	Sample 1	Sample 2	Sample 3
Dry Matter (DM) (g kg <sup>-1</sup> )	290	194	198
pH	4.8	4.0	3.9
Digestibility (DMD)(g kg <sup>-1</sup> )	590	677	624
Crude Protein (g kg <sup>-1</sup> )	141	153	134
Ash (g kg <sup>-1</sup> )	94	88	98
Ammonia N/Total N (g kg <sup>-1</sup> )	139	82	57

The silage represented by Sample 1 is badly preserved and would depress animal intake and performance if it were the only or main feed. Sample 3 represents a mediocre silage which would give a small daily weight gain. Only the silage, represented by Sample 2, is considered reasonably satisfactory.

A visual examination of the three silage samples indicated that they all had conspicuous amounts of Yorkshire fog (*Holcus lanatus*), rough stalked meadow grass (*Poa trivialis*) and bentgrasses (*Agrostis spp.*).

The overall conclusion is that the grassland on this farm is of medium quality for an intensive dairy farm.

### 3.2.2 Other Observations on the Somers Farm.

Mr. Somers sought advice from Teagasc on two occasions on issues of a botanical nature. Both concerned purple colouration of the grass in silage or grazed grass.

1) *Purple veins in grasses in the 1994 silage were observed by Mr. Somers.* The grass was examined and found to be Yorkshire fog (*Holcus lanatus*). Purple veins are a characteristic of the leaf sheaths of Yorkshire fog.

2) *Purpling of grass leaves in the pasture was observed by Mr. Somers in June, 1995.* The affected pastures, pointed out by Mr. Somers, were examined on June 21. Plots that had been recently grazed had little herbage remaining. At the time of the visit there was no grass with purple leaves in these pastures. One of the ungrazed plots, with purple coloured leaves visible, was selected and examined.

The pasture had the general appearance of nitrogen deficiency, *i.e.* pale green colour and relatively poor grass growth. It had a large number of dung and urine patches where more vigorous growth, with dark green grass, was observed. There were no purple tinted leaves observed in the grasses growing in the dung and urine patches.

The pasture had grasses with purple tinted leaves. Visual examination revealed that the tinges were confined to *Lolium multiflorum* (Italian ryegrass). This species of grass is unusual in grazed pastures and is used primarily for the production of silage. It was present only in small amounts. The purpling was more pronounced on the upper sides of the leaves. It was not observed on *Lolium perenne* (perennial ryegrass).

A pink/purple colour is commonly found in *Lolium* species on the leaf sheaths. It is also found in the veins of the leaf sheaths of *Holcus lanatus* (Yorkshire fog). The colour is more pronounced when the plants are exposed to bright light *e.g.* in a sparse or weak sward. The purple leaf tinges on the *Lolium multiflorum* on Mr Somers farm were distinct from the normal colours associated with healthy *Lolium* species.

A total of three grass samples were taken from one field (sample area 5 of the main Teagasc soil and vegetation study, Fig. 5) for analysis. The first sample was *Lolium multiflorum* with purple tinted leaves from the grazing area. The second sample was *Lolium multiflorum*, without purple tinted leaves, from dung and urine patches. The third sample was *Lolium perenne*, without purple tinted leaves, from dung and urine patches. Two other *Lolium multiflorum* samples (from west Cork) with similar purple tints to those observed on the Somers farm were secured and included in the analysis. The samples were analysed as whole plants, leaves only and stem only. The chemical analysis included nitrogen, phosphorus, potassium, magnesium, sodium, calcium, sulphur and manganese. There were no major differences between the analysis results on similar plant parts, except for N (Table 3.5).

**Table 3.5:** Nitrogen analysis ( $\text{g kg}^{-1}$ ) of *Lolium multiflorum* samples taken from Somers farm in June 1995

1. Whole plant (Leaves & Stems)	N
<i>L. multiflorum</i> , Askeaton - purple	18.7
<i>L. multiflorum</i> , West Cork 1 - purple	19.3
<i>L. multiflorum</i> , West Cork 2 - purple	22.9
2. Leaves (Samples from Somers farm only)	
<i>L. multiflorum</i> - purple	20.9
<i>L. multiflorum</i> - green from dunged area	35.4
<i>L. perenne</i> - green from dunged area	37.4
3. Stems (Samples from Somers farm only)	
<i>L. multiflorum</i> - purple	13.4
<i>L. multiflorum</i> - green from dunged area	17.2

The grasses with the purple colouration had lower levels of nitrogen compared with those normally found in *Lolium* species during spring growth (Table 3.5). Leaves or parts of leaves showing symptoms had lower levels of nitrogen than leaves or parts of leaves not showing the symptoms. The West Cork samples, with purple colouration, had low levels of nitrogen similar to those from the affected grass on the Somers farm.

The symptoms observed in the *Lolium multiflorum* are typical of that grass when it is suffering from nutrient deficiency, especially nitrogen and phosphorus. Purpling of the leaves is not common in the slower growing *Lolium perenne* and other grasses compared to *Lolium multiflorum*. The higher growth rate of *Lolium multiflorum* requires a greater nitrogen supply than its slower growing counterparts. Therefore, nitrogen deficiency symptoms are more likely to emerge in the faster growing plants where nitrogen levels are already low.

The conclusion was that a reduced nitrogen supply was responsible for the purple colouration observed on the leaves of *Lolium multiflorum* on the Somers farm in June, 1995.

### 3.3 FARM OF JUSTIN RYAN, TOMDEELY NORTH, ASKEATON

The farm was composed of eight fields and some have been sub-divided for management purposes by electric fences to give 12 paddocks. All of the farm had been grazed during the winter. There was little standing crop of grass on the fields in March. The surface of most paddocks was found to be damaged by poaching (Table 3.6). When visited again on May 15 grass growth was poor and the height of the standing crop had only increased slightly. There were no fields closed for hay or silage at the time of the May visit.

**Table 3.6:** Degree of poaching observed in paddocks on Ryan farm in March 1995

Paddock No.	Degree of Poaching
1	Severe (cows outwintered)
2	Slight
3	Slight
4	Slight
5	Moderate
6	Slight
7	Severe (cows outwintered)
8	Slight
9	Moderate
10	Slight
11	Moderate
12	Moderate

A botanical examination of the farm was carried out on March 21 and again on May 15. The perennial ryegrass cover in each paddock on these two dates is presented in Table 3.7.

Ryegrass cover in late March was 0.18 and had risen to only 0.24 by the middle of May.

A separate herbage sampling of the Ryan farm was conducted for chemical analysis on May 11 (5.2). The botanical composition of these fresh herbage samples was determined at Johnstown Castle. Contribution to the yield of the different grass species present are given in Table 3.3. It shows that there was a mean contribution by the ryegrasses of 0.26. This figure is close to that of 0.24 obtained by qualitative examination of the paddocks (Table 3.7).

The detailed botanical composition is given in Table 3.3. Nine of the paddocks (No. 1, 2, 3, 4, 7, 8, 9, 11, 12) were of the *Centaureo-Cynosuretum* typical sub-association type. Three were of the *Lolio-Cynosuretum* type (No. 5, 6, 10). The *Centaureo-Cynosuretum* paddocks were typically dominated by bentgrass (*Agrostis tenuis*) or Yorkshire Fog (*Holcus lanatus*). The main accompanying species was rough-stalked meadow-grass (*Poa trivialis*). The *Lolio-Cynosuretum* paddocks were dominated by perennial ryegrass (*Lolium perenne*) or by combinations of rough-stalked meadow-grass (*Poa trivialis*), bentgrass (*Agrostis tenuis*), Yorkshire fog (*Holcus lanatus*) and perennial ryegrass (*Lolium perenne*).

All the paddocks, except No. 6, which was reseeded in 1988 were in old permanent pasture.

There were intermittent hedges along the lines of the field boundary walls. The hedges were typically dominated by hawthorn (*Crataegus monogyna*) and blackberry (*Rubus spp.*) (O'Sullivan, 1995). There were signs of localised grazing of hedgerows, particularly in Paddock No. 7 where cows had been outwintered. The two poisonous weeds noted on the farm were cuckoo pint (*Arum maculatum*) and ragwort (*Senecio jacobea*). The cuckoo pint grew along the base of the hedges in several paddocks, notably No. 7 and 9. Ragwort was present in Paddock No. 5, 7, 8, 9, 11 and 12 but the infestation rate appeared low in all cases.

**Table 3.7:** Perennial ryegrass cover on each paddock in March and May 1995 on the Ryan farm

Paddock No.	March 22	May 15
1	0.20	0.30
2	0.20	0.40
3	0.10	0.05
4	0.00	0.10
5	0.20	0.20
6	0.30	0.65
7	(Severely poached)	0.10
8	0.20	0.10
9	0.20	0.30
10	0.20	0.20
11	0.30	0.30
12	0.10	0.20
Mean	0.18	0.24

### 3.3.1 Silage Quality on the Ryan Farm

Two silage samples were taken on March 21 and sent to Teagasc Grange for analysis. The results of the analyses are summarised in Table 3.8.

**Table 3.8:** Feed quality analysis results for two silage samples taken from the Ryan farm in March 1995

Test	Sample 1	Sample 2
Dry matter (DM) (g kg <sup>-1</sup> )	328	298
pH	4.9	5.1
Digestibility (DMD) (g kg <sup>-1</sup> )	637	575
Crude protein (g kg <sup>-1</sup> )	168	123
Ash (g kg <sup>-1</sup> )	99	82
Ammonia N/Total N (g kg <sup>-1</sup> )	174	233

These results indicate badly preserved silage with medium crude protein and low digestibility.

The conclusion is that the grassland on the Ryan farm was from medium to poor quality for an intensive dairy farm with only one paddock having more than 0.50 ryegrass cover on May 11, 1995, and many having less than 0.30.

### 3.3.2 Other Botanical Observations on the Ryan Farm

During a Teagasc visit to the farm in late August 1995 attention was drawn to a whitish encrustation on some of the grassland plants. Two samples, (1) Leaves of dandelion with whitish material on both sides of leaves and (2) Leaves of mainly perennial ryegrass with dusty, whitish deposit on them, were collected from Paddock No. 6 on the farm.

The samples were examined microscopically the next day at Johnstown Castle. The whitish, dusty material on the samples was provisionally identified as a powdery mildew. The two samples were sent on the same day to the Plant Pathology and Entomology Department at Teagasc, Oak Park, Carlow. A third sample was included, namely sow-thistle growing near the laboratories at Johnstown which also had a powdery white material on the leaf surfaces.

The white material on the surfaces of the dandelion and sow-thistle leaves was confirmed as powdery mildew by Oak Park. There were powdery mildew lesions on the grass leaves also. Powdery mildew is favoured by dry warm weather and was very prevalent in 1995.

### 3.4 CONTROL FARM, ASKEATON

The farm is in three separate units, all of which are close to the farmyard and new farmhouse. There is a total of 8 fields but some of them are divided by fences into smaller paddocks. The three highest fields are at an altitude of about 30 m and all the others are at an altitude of between 15 and 20 m. The general topography of the farm is flattish to gently sloping.

All of the farm is in permanent grassland. Paddock No. 8 which is a separate unit furthest from the farmyard is mainly used for silage. All the farm had been grazed up to at least December 1994. On the March visit most fields had a sward cover of at least 0.75 and the general grass height at that time varied between 50 and 100 mm. Poaching damage was minimal in all paddocks.

A botanical examination of the farm was carried out on March 22 and again on May 15. The cover formed by perennial ryegrass on the farm on these two dates is summarised in Table 3.9.

**Table 3.9:** Perennial ryegrass cover on each paddock in March and May 1995 on the Control Farm

Paddock No.	March 22	May 15
1	0.60	0.85
2	0.70	0.85
3	0.75	0.60
4	0.50	0.60
5	0.40	0.40
6	0.50	0.70
7	0.60	0.60
8	0.50	0.30
Mean	0.56	0.61

All the swards were of the *Lolio Cynosuretum* type (Table 3.3). They were all dominated by perennial ryegrass (*Lolium perenne*). The main accompanying grasses were meadow grass (*Poa trivialis* and *Poa annua*), Yorkshire fog (*Holcus lanatus*) and common bentgrass (*Agrostis tenuis*). All the swards were at least 20 years old. Broad-leaved weeds were generally scarce. Broad-leaved dock (*Rumex obtusifolius*) was common in Paddock No. 3, 6 and 8 when visited in March.

The paddocks were typically surrounded by hawthorn (*Crataegus*) hedges. There were occasional trees, generally of ash (*Fraxinus*).

There was no sign of any grazing by livestock of either the hedgerows or the vegetation on the walls and banks. No poisonous species were noted, either in the fields or along the boundaries except for a trace occurrence of cuckoo pint (*Arum maculatum*) at the edge of Paddock No. 1. Ragwort (*Senecio jacobea*) was scarce or absent from most paddocks.

### 3.4.1 Silage Quality in the Control Farm

Two silage samples were taken March 21 and sent to Teagasc Grange for analysis. The results are summarised in Table 3.10.

**Table 3.10:** Feed quality analysis results of two silage samples taken from the Control farm in March 1995

Test	Sample 1	Sample 2
Dry Matter (DM) (g kg <sup>-1</sup> )	226	214
pH	3.7	3.9
Digestibility (DMD) (g kg <sup>-1</sup> )	658	671
Crude protein (g kg <sup>-1</sup> )	164	167
Ash (g kg <sup>-1</sup> )	81	89
Ammonia N/Total nitrogen (g kg <sup>-1</sup> )	80	100

These results indicate a well preserved silage with adequate crude protein and of medium quality as regards digestibility. The two silage samples were also botanically examined. The two samples had a high proportion of leaf and perennial ryegrass was plentiful in them.

The conclusion is that grassland on this farm is of high quality typically associated with good dairy farms. There was no evidence of any significant infestations in the pastures and hedgerows by poisonous plants.

## 3.5 ADDITIONAL BOTANICAL INVESTIGATIONS 1995

The Somers farm was visited on August 23<sup>rd</sup>, 1995. A brief visual assessment of the trees on the farm was undertaken. The farm is moderately exposed to the prevailing southwest and west winds, being situated close to the Shannon estuary. It should be borne in mind that the survey was carried out after a prolonged and very sunny dry spell which has placed trees all over the country under stress.



### 3.5.1 Conifer Trees

Several conifer trees (cypress species), of approximately 5-8 m in height, situated near the Somers farm entrance were dead (Plate 2). Cypress trees are mostly grown for decoration and are generally not considered as commercial forest trees in Ireland. Lawson's cypress is hardy to spring frosts but is not suitable for use on exposed sites. Unlike many conifers it withstands atmospheric pollution well. Some cypress species are known to be intolerant of exposure and salt pollution. One tree still had a portion of live material with a live crown and one live side branch on the sheltered side. There was no sign of any physical damage or disease on the live portion of the tree which looked healthy. It was not possible to make any definite assessment of the cause of death of these trees. A possible cause of death is exposure. A nearby Monterey cypress, which is tolerant of both sea coast conditions, salt spray and exposure, was showing no obvious sign of damage.

Another row of cypress of a different variety along the driveway into the farm are healthy but show signs of dieback of the lower branches which is typical for this variety.

Other conifers in the immediate area were mostly healthy but showed signs of climatic exposure.

### 3.5.2 Broadleaved Trees

The hawthorn hedgerow trees showed some signs of twig die back, particularly on the exposed side, but this is typical for this species in exposed areas. Similar defoliation of very small twigs can be seen at the Teagasc Research Centre in Kinsealy, Co. Dublin.

The ash in the hedgerows looked healthy.

At the Ryan farm sycamore trees at the entrance, which were pointed out, were suffering from Tar Spot and Leaf Blister and some aphids were present. All of these, pest and diseases, are common on sycamore. There was also some browning of the leaf edges which has been observed elsewhere in the country. It may be attributed to sun scorch or drought. Some of the trees on the driveway showed crown thinning with some shoot die-back. These were mature trees some of which may have been disturbed by widening of the driveway to the house, which if it caused damage to the roots, would lead to some crown death.

A decorative willow on the site was showing a stem infecting form of *melampsora* rust which is becoming a virulent pathogen on willow. Such infections lead to cankers, shoot-die-back and wind snap of affected branches.

Recently planted trees and shrubs were showing signs of drought which may have been aggravated by grass competition. The grass had been mown which would tend to exacerbate the competition for moisture and nutrients.

### 3.5.3 Detailed Assessment

This was a preliminary and brief visual assessment of the condition of the trees in the local area. A definitive assessment of tree health in this area would require considerable time and would need to be carried out by a qualified team of foresters and pathologists. Even the exact identification of the particular varieties of cypress would require the assistance of the dendrologists at Kew gardens.

## References

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## CHAPTER 4

### SOIL ANALYTICAL RESULTS

#### 4.1 INTRODUCTION - INVESTIGATION OF SOMERS, RYAN AND CONTROL FARMS - SOILS

A short review of the role of major and trace elements in soils and plants is presented here. The identity of the major elements, essential trace elements and contaminant heavy metals encountered most frequently, together with their respective levels in soils and herbage, are presented. The database on elemental levels is more complete for some elements than for others. The factors that most influence their activity and toxicity in soil and their accumulation by plants are described. The review describes the practice of using chemical extractants to assist in the prediction of uptake of nutrients/heavy metals by plants from soils. Procedures used for the sampling, preparation for analysis and analysis of soils, are described. Following this, soil chemical analysis data for Somers, Ryans and the control farm are given and discussed.

##### 4.1.1 Major And Trace Elements In Soils (and Plants)

The soil is an essential medium for the growth of plants and for the breakdown and recycling of organic matter. Soils are considered the most important environmental compartment functioning as a sink for trace elements (Senesi *et al.* 1999). Changes in soil properties such as pH, redox potential and moisture status can affect the bioavailability and form of the elemental components of the soil. Soils are reasonably stable but become progressively more acid due to the action of dissolved carbon dioxide. Acidity (low soil pH) can be adjusted to optimum levels for crop production by additions of lime. Metal cations are more active under acid conditions and increases in pH reduce their bioavailability. Conversely anions, for example molybdate, become more available with increase in pH.

Large transfer of elements, including metals, to soil systems will change not only the chemical properties but will also influence the physical and biological properties of the soil. Certain metals including Cu, Zn and Ni, at moderate levels are also harmful to micro-organisms and may affect essential soil processes (McGrath, Chaudri and Giller, 1995).

Metal pollution can include two categories of harmful effects to higher life forms. In the first category the concentration in plant or in the soil could reduce growth of vegetation by phytotoxic effects. Secondly, the concentration present may not affect the growth of vegetation but could constitute a health hazard to those who consume it.

Elemental uptake by plants is influenced by factors controlling (1) the level and chemical form of the element (speciation) in the soil (2) the movement of the element to the root (3) the absorption of the element into the root and (4) the translocation from the root to the plant shoot. In addition to root absorption, plants can also take in significant amounts of the same elements by leaf absorption and this can be the route of entry by atmospheric pollutants. The readiness of deposited particles to enter through the leaf surface obviously depends on the particular metal; for example zinc can enter plants more readily through foliar absorption than can lead or copper (Little, 1973).

Nearly ninety chemical elements may be found in soils and plants. Many may be quite toxic even at low levels of intake, whereas others are relatively innocuous. The elements which are essential for life are those which cannot be wholly replaced by any other element. If a particular organism does not have a certain minimum supply of an essential element it cannot complete its life cycle. In this respect the trace elements are as important as the major elements - the principal difference is that they are required in

much lower quantities. The elements are for convenience divided into major elements and trace elements. The dividing line is usually set at 0.1 percent or 1,000 milligrams per kilogram; this is a purely arbitrary limit.

#### 4.1.2 Ranges of Elements in Soils

As may be expected, elements vary in concentration in different soils. In the case of trace elements (including heavy metals) this variation may often be 100 fold or more. The ranges in content of a number of elements in soils are shown in Tables 4.1 and 4.2. The levels are given in  $\text{g kg}^{-1}$  for the major elements and as  $\text{mg kg}^{-1}$  for the trace elements. Data on some of these elements in Irish soils is relatively limited. The ranges given are those encountered in Irish agricultural soils. Much higher levels may be encountered in the vicinity of ore deposits (DAFRD, 2000) and in industrial areas.

Urban soils tend to have much higher concentrations of metal elements than do rural soils. Garden soils, particularly those from old gardens, tend to have relatively high metal contents (McGrath, 1994).

#### 4.1.3 Extractable Trace Elements in Soils

Total content of an element in soil - whether major or trace - is not a good guide regarding its availability to the growing plant. Therefore, a range of empirically derived extraction procedures have been developed to simulate the availability of elements to plants. The extraction techniques used for soils employ reagents whose extractable content correlates with the plant-available content of the soil and so can be used to predict plant uptake or the possibility of deficiency or toxicity symptoms occurring in plants or animals. This approach is well established in soil science for predicting the uptake at normal concentrations of essential and potentially toxic elements (Martens and Lindsay, 1990; Risser and Baker, 1990).

The reagents used are relatively mild extractants and they may vary for each element. It is important to realise that, whereas extractable contents give a better index of availability they are by no means perfect and their ability to predict likely plant contents is dependent on a number of soil factors e.g. pH, organic matter content, and soil texture. Table 4.3 gives the normal ranges of elements extracted with conventional extractants. These data have been accumulated over many years and represent the position as it is known at present.

**Table 4.1:** Typical ranges ( $\text{g kg}^{-1}$ ) of major elements in non-polluted Irish agricultural soils (total contents)

Element	Symbol	<sup>1</sup> Range (1)	<sup>2</sup> Range (2)
Aluminium	Al	10.00-80.00	7-89
Calcium	Ca	5.00-30.00	-
Iron	Fe	10.00-50.00	3-59
Magnesium	Mg	1.00-15.00	0.4-18
Nitrogen	N	1.00-4.00	-
Phosphorus	P	0.20-2.00	-
Potassium	K	1.00-30.00	3-25
Silicon	Si	150-400	-
Sodium	Na	0.50-15.00	-
Sulphur	S	0.20-1.50	-

<sup>1</sup>Range (1). P. Parle, personal communication, 1995; <sup>2</sup>Range (2). McGrath and McCormack, 1999

**Table 4.2:** Typical ranges (mg kg<sup>-1</sup>) of trace elements in non-polluted Irish agricultural soils (total contents)

Element	Symbol	<sup>1</sup> Range (1)	<sup>2</sup> Range (2)
Antimony	Sb	0.2-3.0	-
Arsenic	As	1-50	3-104
Boron	B	20-1000	-
Cadmium	Cd	0.1-1	0.01-3.2
Chlorine	Cl	30-300	-
Chromium	Cr	5-250	3-323
Cobalt	Co	1-25	1-53
Copper	Cu	2-100	2-73
Fluorine	F	20-700	-
Iodine	I	2 - 20	2.5-16
Lead	Pb	2-80	10-100
Manganese	Mn	20-3000	20-5167
Mercury	Hg	0.03-0.8	0.03-1.0
Molybdenum	Mo	0.2-3	-
Nickel	Ni	0.5-100	1-150
Selenium	Se	0.2-2	0.2-9.7
Thallium	Tl	0.1-0.5	-
Tin	Sn	1-40	-
Uranium	U	1-10	-
Vanadium	V	20-250	-
Zinc	Zn	10-200	4-239

<sup>1</sup>Range (1). P. Parle, personal communication, 1995

<sup>2</sup>Range (2). McGrath and McCormack, 1999

**Table 4.3:** Typical ranges of extractable elements in non-polluted Irish agricultural soils

Element	Extractant <sup>1</sup>	Content (mg l <sup>-1</sup> )
Phosphorus	Acetic acid - sodium acetate	1 - 20
Potassium	Morgan's reagent (pH 4.8)	50 - 300
Magnesium		30 - 400
Sodium	Ammonium acetate	20 - 100
Sulphur	Calcium phosphate	<10.0 - 50
Manganese (easily reducible)	Calcium nitrate and 0.2% Quinol	10 - 600
Copper	EDTA (pH 7.0)	1.0 - 20.0
Zinc		2.0 - 15.0
Molybdenum	Ammonium oxalate/oxalic acid Tamm's reagent (pH 3.3)	0.1 - 1.0
Boron	Hot water	0.1 - 4.0

<sup>1</sup> Extractants are described by Byrne (1979)

#### **4.1.4 Effects Of Aerial Contamination On Soil And Herbage**

In this section, types of contamination likely to be experienced on farms, and that may lead to an increase of chemicals (mainly inorganic) in soil and herbage, are considered.

The composition of both soil and herbage can vary quite considerably with the variability of the former being generally much greater than that of the latter. There is no such thing as a standard soil and many soils have an excess or deficiency of one or more elements that are required for good plant growth and animal health.

In suspected soil/herbage contamination cases, especially where animal ill-health or death occurs, at least three scenarios fall within the remit of the chemist. These comprise (1) events involving emission and deposition (2) natural (geochemical) pollution or contamination by mining or dumping (3) direct or induced mineral deficiencies.

#### **4.1.5 Pollution of Herbage/Soil by Aerial Deposition**

Industry has been and still is responsible for the emission of a wide range of solids and gases (Burton, 1986). The former include largely inert materials from earth moving activities (quarrying, mining) but may also include mining residues containing heavy metals, or products of incomplete combustion e.g. soot. Gaseous emissions and their products include acid-forming gases, i.e. oxides of sulphur and nitrogen, hydrofluoric acid, hydrochloric acid and ozone. All of the above, at a sufficiently high concentration, can have a visible effect on plants (Guderian, 1977). Most, with the possible exception of nitrogen oxides and ozone, may in practice affect animals and have been implicated in incidents involving farm and wild animals (National Research Council, 1991; Samiullah, 1990).

Smelting and combustion may also cause the volatilisation of some metals especially mercury, cadmium and lead in addition to acid gases. Organic substances, particularly solvents may also be released in variable amounts. Insecticides, especially are continually being implicated in acute toxicity events in underdeveloped countries (Knott and Day, 2000). Immediate effects following explosive dispersion of chemicals and their derivatives as in Bhopal in 1984 and Seveso in 1976 have received widespread publicity, but are of infrequent occurrence. Emissions from discarded solvents and from petroleum refineries have been implicated in reported chronic incidents. When it comes to long-term chronic effects, the list of possible influential emissions lengthens for animals, especially humans, but not to the same extent for plants.

In Ireland a number of proven instances of emissions influencing soil or herbage have been documented. Greatly increased levels of lead in soil have been demonstrated for one mining area (DAFRD, 2000); deposited lead on herbage has been reported in another (Donovan et al, 1968). Animal deaths had been authenticated in both these areas and were attributed to lead poisoning.

Also in Ireland, significant gaseous emissions have been found for hydrofluoric acid (used for glass-etching) and in earlier years sulphur dioxide generated from pyrites or in superphosphate production. The former constituted a risk to animal health from excess hydrofluoric acid deposited on vegetation. High sulphur dioxide levels associated with the phosphate fertiliser plant is known to have caused considerable damage to vegetation.

In general elsewhere, very serious metal emissions tend to be confined to smelters and superphosphate plants. Gaseous emissions are associated with smelters, superphosphate plants and brickworks. This is not a comprehensive list, as even localised industries can cause serious emissions, i.e. where mercury is used in gold prospecting, emissions tend to leave only a minor impression on soil compared to herbage. Very high sulphate levels have been found in soils (Meshalkina et al., 1996) in affected areas. Sulphur acid deposition also causes acidification of soils. This can result in leaching of essential elements

especially in light textured soils. Very acid soils require amelioration with lime before crops can again be grown. pH elevation also reduces the availability of many trace elements. In parts of the US this process has produced crops (for example, alfalfa) containing extremely low levels of manganese. This in turn has resulted in illness and death of ruminants due to manganese deficiency or refinery smoke syndrome as it has been called (Cowgill et al, 1980).

Overall, outside of long established heavy dirty industry, aerial emissions occurring in amount sufficient to influence soil and vegetation are rare. In Teagasc's experience in recent years in Ireland chemically measurable effects have been confined to dust or soil from mine working on herbage and to hydrofluoric acid from glass etching on herbage. Vegetation is susceptible to large number of other effects, physical, climatic, seasonal and disease. Visible symptoms displayed by plants are much more likely to result from these causes than from polluting influences. This is not to deny that emissions do occur – where fuel is burned, sulphur dioxide is formed and metals are volatilised. It is saying that such emissions now generally have little impact on the composition of soil and plants.

#### **4.1.6 Geochemical Pollution**

Some soils are heavily polluted. In mining areas it is difficult to separate natural (geochemical pollution) from pollution caused by historic mining activities especially in areas that have been naturalised over the years. Some of this pollution is quite extensive but some occurs in small pockets. Levels of metal, lead, zinc and copper can be sufficiently high to effect animals *via* ingestion of soil but not normally of soil-free herbage. Parts of the country experience low level enrichment of these and other metals in soil. Such areas include parts of Limerick and Clare as well as some Midland counties. A special instance of poisoning results from selenium which has accumulated in small pockets in peaty soils especially in Counties Limerick and Meath. Consumption of herbage grown in these areas can cause sporadic injury and even death to cattle. In these regions, other metals and especially cadmium have also been found at potentially dangerous levels in soil. Frequency of occurrence of any of these pollutants in toxic amounts is not large but effects can be serious. Perhaps a milder but much more extensive level of pollution relates to molybdenum, which is not in itself toxic but which interferes with copper absorption by ruminants, and this will be referred to below.

#### **4.1.7 Mineral Deficiency**

Trace elements in Irish mineral soils are generally sufficient to sustain grass growth. However, mineral deficiencies may occur on farms and may impinge on animal performance and health. They include principally cobalt, selenium, iodine and copper (Rogers and Keating, 1994). Other soil components interact with these nutrients, at plant or animal level. Interactions include interference by manganese in soil with cobalt uptake by plants and interference by molybdenum but also zinc, iron and sulphate with absorption of copper by animals from ingested herbage. Many soil nutrients, both major and trace, are relatively permanent although they need replenishment to varying degrees. However, as indicated above, some are especially transitory – i.e. iodine, selenium, and sulphur.

Whereas many industrial pollutants, and particularly those with major impact, are deposited close to their emission point, many have long range (after transboundary) effects. Some are noxious but others may have a positive effect. Among the former may be listed lead (from petrol additive) mercury and perhaps sulphur. Among the positives may be selenium and iodine. Some would now be tempted to transfer sulphur to the positive list as sulphur deficiency in grassland has been recognised in Ireland for many years (Murphy and Boggan, 1988) and is now regarded as commonplace even in industrialised areas (Bristow and Garwood, 1984).

## 4.2 SOIL SAMPLING PROCEDURE

Soil sampling procedures vary in respect of a) sampling depth, b) area represented by each sample and c) number of sub-samples in each sample. Despite the variability of published protocols it is the Teagasc view, and one generally held, that the actual procedures used should be tailored to the circumstances of each case.

For agronomic purposes, Johnstown Castle stipulates that i) samples be taken to a depth of 100 mm; ii) the maximum area represented by each sample is an area of two to five ha, or one enclosure whichever is the smaller; iii) at least 20 cores be taken in a W-shaped pattern across each sampled area and combined to constitute a sample. In the present case, the fields were inspected and divided into 2 to 3 ha sized units before sampling. The outlines of each area were measured and marked off on the appropriate farm map (Figs 8, 9 and 10).

In 1995 soils were sampled to a depth of 50 mm. At least 100 soil cores were taken from each sampling unit. The primary objective was to obtain evidence of aerial deposition of contaminants. A depth of 50 mm was the minimum that could be conveniently and accurately sampled. This was the sampling depth used in previous baseline surveys conducted in the area. However, it meant some loss of comparability against standard Johnstown Castle agronomic data on grassland soils. This loss will be more important for pH and extractable phosphorus and potassium than for other soil chemical parameters. pH is normally lower in the 0 to 50 mm horizon than in the 50 to 100 mm horizon. Phosphorus and potassium levels will be higher at 0 to 50 mm, as a consequence of ongoing fertiliser applications, compared with the 0 to 100 mm layer.

At the same time, samples (0-50 mm) including sod were taken to a depth of 0-50 mm, using a stainless steel trowel, and specially cleaned glassware (washed with residue-free hexane). About 10 replicates were taken and combined to form a single bulk (ca 2 kg) sample. Sampling locations (2 per site) are shown in Figs 8-10. Samples were forwarded to the EPA for special analyses of persistent organic pollutants. A second sample was taken from the same locations for PCB (polychlorinated biphenyl) analysis.

## 4.3 ANALYTICAL METHODS

Before analysis, soils and sediment were dried at 40°C in a forced draught oven ground gently and sieved to pass a 2 mm sieve.

A brief description of the analytical methods used for soils and sediments is given in Appendix 1. In general, extraction and estimation procedures in common use at Johnstown Castle were followed. These approximated to those described by Byrne (1979) with amendments to accommodate newer extraction (e.g. microwave) and estimation (e.g. electrothermal atomic absorption) techniques.

The accuracy of each method was verified by the use of standard reference materials for which the accepted values of the analyte concentrations were established either internationally, *i.e.* BCR (EU) or NBS (U.S.), or in exceptional cases, by in-house studies.

Except where otherwise stated soil results are expressed on an air-dried basis.

The remainder of this chapter is devoted to results of chemical analysis following the intensive sampling of soils on Somers, Ryan and Control Farms in March 1995. Additional information is included on the following; fluorine in Irish and Askeaton soils, fluorine and selenium variation with depth in two soil

profiles on the Somers Farm, analysis following re-survey of the Somers farm in December 1997, and sediments from streams and troughs taken in March 1995 from the three farms.

#### 4.4 MOISTURE, LOSS ON IGNITION, pH, LIME REQUIREMENT AND MACRONUTRIENTS

All results, except loss on ignition, a measure of organic matter, are uncorrected for soil moisture content. Moisture values were determined and are presented in Appendix 2.1. Moisture values generally ranged from 20 to 40 g kg<sup>-1</sup> and corrections for this would have no significant impact on the results presented. Organic matter values (Appendix 2.1) were above the average of about 100 mg kg<sup>-1</sup> for the country (Brogan, 1966). The Somers Farm in particular had areas (Plots 9-11) that were water-logged and enriched in organic matter (Appendix 2.2).

The pH, lime requirement, and extractable calcium, phosphorus, potassium, magnesium, sodium and sulphate-sulphur values are recorded in Appendix 3 and are summarised in Table 4.4. All values fall within the ranges typical of Irish grassland soils. Some care is required in comparing these results with normal soil test results to 100 mm especially for phosphorus and potassium because of the shallower sampling depth (4.2).

On the Somers farm soil pH values and lime requirement values were optimum for grass growth: lime application on this farm had been made in the mid-eighties. About one third of samples from the Ryan farm and all the samples from the Control farm fell into the low pH categories.

Soil phosphorus and potassium reserves on both Somers and Ryan farms were in general satisfactory. About 0.40 of samples on the Control farm were low with respect to phosphorus and 0.20 were low with respect to potassium. Magnesium, sodium and sulphur soil values were satisfactory on all three farms. Sulphur (in the form of sulphate) is known to have maximum values in late winter. In normal soils sulphate amounts are generally significantly related to organic matter (loss on ignition). Regression analysis of sulphate S on loss on ignition indicated a highly significant overall relationship ( $r = 0.57$ ;  $P \leq 0.01$ ). It is not considered that S levels found indicated a significant level of pollution especially as sulphate is at a maximum in soil in early spring before plant regrowth (M. Murphy, personal communication, 1996), the time of year that sampling took place.

**Table 4.4:** Summary of the mean pH, lime requirement (L.R.) loss on ignition and extractable calcium (Ca), phosphorus (P), potassium (K), magnesium (Mg), sodium (Na) and sulphur (S) values of soils on each farm

	Somers	Ryan	Control
pH (H <sub>2</sub> O)	6.6	6.0	5.7
Loss on Ignition (g kg <sup>-1</sup> )	146.4	134.4	122.1
LR (t ha <sup>-1</sup> )	2.1	8.2	11.2
P (mg l <sup>-1</sup> )*	8	8	4
K (mg l <sup>-1</sup> )*	133	139	130
Mg (mg l <sup>-1</sup> )*	189	212	163
Na (mg l <sup>-1</sup> )*	24	28	25
S (mg l <sup>-1</sup> )*	21	17	15

\*Following the convention of taking a fixed volume of dried soil for these analyses



## 4.5 EXTRACTABLE SOIL MICRONUTRIENTS

The mean values obtained for the extractable soil micronutrients manganese, copper, zinc, boron, molybdenum are summarised in Table 4.5. The full results are presented in Appendix 4.

**Table 4.5:** Summary of the mean soil manganese (Mn), copper (Cu), molybdenum (Mo), zinc (Zn), and boron (B) levels ( $\text{mg l}^{-1}$ ) on the Somers, Ryan and Control farms

	Somers	Ryan	Control
Mn	202	422	278
Cu	5.9	3.9	4.6
Mo	0.33	0.27.	0.26
Zn	4.5	6.3	5.6
B	1.1	1.1	0.8

The level of extractable manganese was lower on the Somers farm than on both the Ryan and Control farms. This is mainly a reflection of the higher pH values. However, the values on the three farms were satisfactory from an agronomic perspective.

In general, the soil copper levels on the three farms appear sufficient ( $\geq 3 \text{ mg l}^{-1}$ ) to meet the needs of the animals grazing the pasture. However, two samples from the Ryan farm had slightly lower levels than this (Appendix 4.2).

The mean molybdenum values on the Ryan and Control farms were similar to the mean value obtained by Brogan *et al.* (1973) in a countrywide survey. Soil samples taken from the low lying area of the Somers farm had elevated molybdenum levels (Appendix 4.1).

For zinc all values fell within the excepted range. In general, the extractable zinc values on the Somers farm well lower than those on the other two farms. This is a reflection of the higher pH values on this farm (Table 4.4).

The boron levels on the three farms were satisfactory.

In summary, there was nothing unusual with regard to the extractable micro-nutrients, manganese, copper, molybdenum, zinc and boron values. In particular, there are no values which indicated a likely abnormal level in herbage.

## 4.6 TOTAL SOIL MICRONUTRIENTS

As there are no fully evaluated extractants for iodine, selenium and fluorine, their contents are reported as total values. Total cobalt values when viewed in conjunction with total manganese values can be a good indicator of uptake of cobalt by plants. The full results are given in Appendix 5 and they are summarised in Table 4.6.

Soil iodine values on the three farms were consistent with Irish soil values found by McGrath and Fleming (1988).

The selenium content of the soil from the three farms were mainly low but fell within the range obtained for non-seleniferous Irish soils (Parle *et al.*, 1995). Three samples from the low-lying area of the Somers farm had elevated values. These higher values were from areas found to be enriched in alluvium (2.2). However, these higher levels were below those that could constitute an animal health problem (Mayland, 1994).

The Somers and Control farms are satisfactory with regard to cobalt status. In a survey of 522 Irish soils derived from varying parent materials, Fleming and Parle (1987) obtained an overall cobalt mean value of 5.2 mg kg<sup>-1</sup> with a mean of 6.0 mg kg<sup>-1</sup> for limestone soils. Although the soils from the Ryan farm have adequate cobalt values, the slightly elevated manganese levels in these soils (Table 4.6) will reduce cobalt availability to plants (Fleming, 1983).

**Table 4.6:** Summary of mean soil iodine (I), selenium (Se), cobalt (Co), manganese (Mn) and fluorine (F) levels on the Somers, Ryan and control farms. (mean values mg kg<sup>-1</sup>)

	Somers	Ryan	Control
I	6.0	7.7	8.5
Se	1.20	0.54	0.50
Co	7.1	8.9	8.7
Mn	359	756	479
F	984	675	697

Mean fluorine values for the soils from the Somers, Ryan and Control farms are 984, 675 and 697 mg kg<sup>-1</sup>, respectively. These values appear high compared to mean values of 300-400 mg kg<sup>-1</sup> for UK soils (Fuge and Andrews, 1988). No information was available on fluorine levels in Irish soils. Therefore, as part of this investigation, fifteen additional samples were selected at random from soil received for analysis at Johnstown Castle and were analysed. Results are presented in Table 4.7.

**Table 4.7:** The fluorine content (mg kg<sup>-1</sup>) of Irish soils

County	No. of Samples	Fluorine
Tipperary	1	370
Roscommon	1	540
Offaly	2	470, 490
Dublin	1	470
Donegal	1	540
Galway	1	300
Louth	1	310
Waterford	1	250
Wexford	2	300, 280
Mayo	1	680
Limerick	3	680, 700, 540
Mean		461

The mean value for soil fluorine was 461 mg kg<sup>-1</sup> which is comparable with the reported UK values. However, the levels in the Limerick soils were consistently higher. A further series of fluorine determinations were made from soil archival samples, 4 taken from N, S, E and W of each of the Askeaton Farms. These soils had been sampled in 1979 as part of the Aughinish baseline survey (Fleming and Parle, 1983). They were found to have significantly elevated fluorine levels (Table 4.8) with means of 760, 578 and 760 mg kg<sup>-1</sup> associated with Somers, Ryan and Control Farms, respectively.

In summary, iodine, cobalt and selenium levels are typical within the range for Irish soils. However, selenium values for some samples suggest a possible deficiency of this element whereas some selenium values on the Somers farm are indicative of geochemical pollution. Fluorine levels appear elevated. However, generally soils in the region appear to have high levels of this element.

**Table 4.8:** Fluorine content (mg kg<sup>-1</sup>) of soil samples taken in 1979 as part of the Aughinish Baseline Survey

Location and Ident No.	Fluorine
Somers Farm (AAH 277)	640
Near Somers (AAH 272)	620
Near Somers (AAH 276)	980
Near Somers (AAH 285)	<u>800</u>
Mean	760
Ryan Farm (AAH 302)	600
Near Ryan (AAH 205)	490
Near Ryan (AAH 206)	620
Near Ryan (AAH 294)	<u>600</u>
Mean	578
Near Control (AAH 290)	800
Near Control (AAH 291)	800
Near Control (AAH 293)	640
Near Control (AAH 295)	<u>800</u>
Mean	760

#### 4.7 IRON, ALUMINIUM AND TITANIUM

Iron, aluminium and titanium values for total contents of the soil are presented in Appendix 6 and are summarised in Table 4.9. All three elements fall within the typical ranges reported for Irish soils, with little variation between the soils from the three farms. Aluminium is toxic to plants in very acid soils. Its toxicity is essentially pH dependant and increases exponentially below a pH of 4.5 (Anderson, 1988). Symptoms of toxicity develop initially in the roots: subsequent effects vary with plant species but generally resemble those associated with nutrient deficiency, particularly that of phosphorus.

**Table 4.9:** Total iron (Fe), aluminium (Al) and titanium (Ti) (mg kg<sup>-1</sup>) in soil on the Somers, Ryan and Control farms

	Somers	Ryan	Control
Fe	24120	20441	21812
Al	40744	38037	39593
Ti	6315	5547	5747

#### 4.8 HEAVY METAL CONCENTRATIONS IN SOIL

Copper, zinc, chromium, nickel, vanadium, cadmium, lead, thallium, mercury and arsenic were determined (Table 4.10) and complete values are recorded in Appendix 7. The metal concentrations fall within typical ranges for these elements. There is a distinct area on the Ryan farm (Plots 3-8), where the zinc, cadmium, lead, and arsenic values are comparatively elevated but this was considered to have no significance. Nickel values on all three farms are higher than in most Irish soils although not unlike those in Kildare (McGrath and McCormack, 1999).

**Table 4.10:** Mean total heavy metal concentrations (mg kg<sup>-1</sup>) of copper (Cu), zinc (Zn), chromium (Cr), nickel (Ni), vanadium (V), cadmium (Cd), lead (Pb), mercury (Hg) and arsenic (As) in soil on the Somers, Ryan and Control farms

	Somers	Ryan	Control
Cu	22.5	16.6	17.2
Zn	78	106	94
Cr	60	43	47
Ni	50	43	45
V	69	56	46
Cd	0.45	0.62	0.38
Pb	20	38	25
Hg	0.12	0.10	0.08
As	12.7	15.4	13.5

#### 4.9 SELENIUM AND FLUORINE IN SOIL PROFILES

In order to confirm that the mild enrichment of selenium and fluorine in soils on the Somers farm were not due to aerial deposition, soil on paddock was sampled at various depths from surface to 225 mm (Profile 1) and from surface to 175 mm (Profile 2) - depths roughly equivalent to the plough layer. The results (Table 4.11) showed no variation with depth indicating that selenium and fluorine did not significantly increase in this soil since it was last tilled.

**Table 4.11:** Selenium and fluorine content ( $\text{mg kg}^{-1}$ ) of soil from two profiles from the Somers farm.

Profile	Depth (mm)	Se	F
I	0-12.5	0.60	840
	12.5-25	0.60	720
	25-50	0.65	790
	50-75	0.60	900
	75-125	0.60	900
	125-175	0.66	900
	175-225	0.65	900
II*	0-12.5	0.55	840
	12.5-25	0.50	860
	25-50	0.50	820
	50-75	0.55	860
	75-125	0.55	860
	125-175	0.55	860

\*Elevation higher than at I

#### 4.10 SUMMARY

In summary, the major agronomic difference between the farms was the higher pH on the Somers farm, compared to the other two farms. On the former, pH was optimum for growth of ryegrass. However, uptake of minerals such as copper is reduced at higher pH. Nevertheless extractable copper values were higher on this farm than on the other two farms.

The Somers farm differs from the other two farms in having elevated selenium, especially on three paddocks. This is an instance where a positive nutritive effect may be attributed to (geochemical) pollution. It may be argued that soil selenium is low on the other two farms but values recorded, at ca  $0.50 \text{ mg kg}^{-1}$ , are the norm in other areas including most of Counties Tipperary and Kilkenny (McGrath and McCormack, 1999).

The fluorine content of soils was high. Prior to this investigation essentially, no information was available on fluorine levels in Irish soils. For this reason a survey was carried out on (a) soils from different parts of the country and (b) archived soils from the Askeaton Baseline Survey (Fleming and Parle, 1983). Measurements confirmed (a) that fluorine levels were indeed elevated in Askeaton soils and particularly on the Somers farm and (b) that similarly elevated levels were present in soils adjacent to this farm in 1979, predating the building of the industrial plant at Aughinish Island.

Fluorine in soil is generally present in fluoroapatite and in hydroxysilicate minerals, and has very low environmental impact (Fuge and Andrews, 1988) and, at the concentrations found in Askeaton, would not be considered a hazard to grazing animals.

By examination of two soil profiles on the Somers farm it was further demonstrated that both fluorine and selenium had exactly the same concentration in top soil as in lower soil depths. This eliminated the likelihood of aerial deposition of either element having occurred in recent years.

Concentration of sulphate-sulphur was normal for soils in early spring (M. Murphy, Personnel Communication, 1995).

It was noted that elevated Ni levels are a feature of soils locally and perhaps of Co. Limerick in general. Soils containing more than 30 mg kg<sup>-1</sup> of nickel may not legally receive sewage sludge when used in agriculture under the provisions of the Waste Management Regulations (SI 148 of 1998). There is no suggestion that they present a hazard. Soil in parts of Scotland and Northern Ireland derived from serpentine and basalt minerals, respectively, are known to contain much higher levels of this element.

#### 4.11 RE-SAMPLING AND RE-ANALYSIS OF SOILS ON SOMERS FARM, NOVEMBER 1997

The Somers farm was re-sampled in the same manner as in 1995, except that on the re-sampling in November 1997, cores were taken to a depth of 100 mm instead of 50 mm. Soils were analysed for major extractable nutrients and for cobalt and manganese (Appendix 8). The main objective of this exercise was to ensure that the fertility status of the farm had not been depressed since 1995. Comparison of the 1995 against the 1997 data (Table 4.12) showed a good agreement for each soil parameter, especially when allowance is made for sampling depth and time of year.

**Table 4.12:** Comparative values for soil (0 – 50 mm depth) sampled in March 1995 and soil (0 – 100 mm depth) sampled in November 1997.

Analyte	March 1995	November 1997
LR	2.1	2.6
P	8.2	4.7
K	133	73
Mg	189	167
Cu	5.9	5.9
Zn	4.5	4.6
Co	7.1	8.1
Mn	359	529

#### 4.12 SEDIMENT SAMPLES

On the Somers farm, two sediment samples were taken - from a stream and a drain. On the Ryan farm three samples were taken, one from a stream and two from water troughs. On the Control farm one sample was taken from a water trough (Fig. 11, 12 and 13).

The following elements were determined on the sediments - mercury, selenium, arsenic, chromium, lead, iron, nickel, cadmium, cobalt, vanadium, titanium and thallium. The analytical data are recorded in Appendix 9.

All values fell well within the ranges of soil samples received at Johnstown Castle. An elevated selenium value of 2.65 mg kg<sup>-1</sup> was obtained for the sediment from the stream on the Ryan farm. A second elevated selenium value of 4.65 mg kg<sup>-1</sup> was recorded for the sediment in the water trough on the Control farm. Selenium values in excess of 100 mg kg<sup>-1</sup> have been reported for West Limerick stream sediments (Webb and Atkinson, 1965).

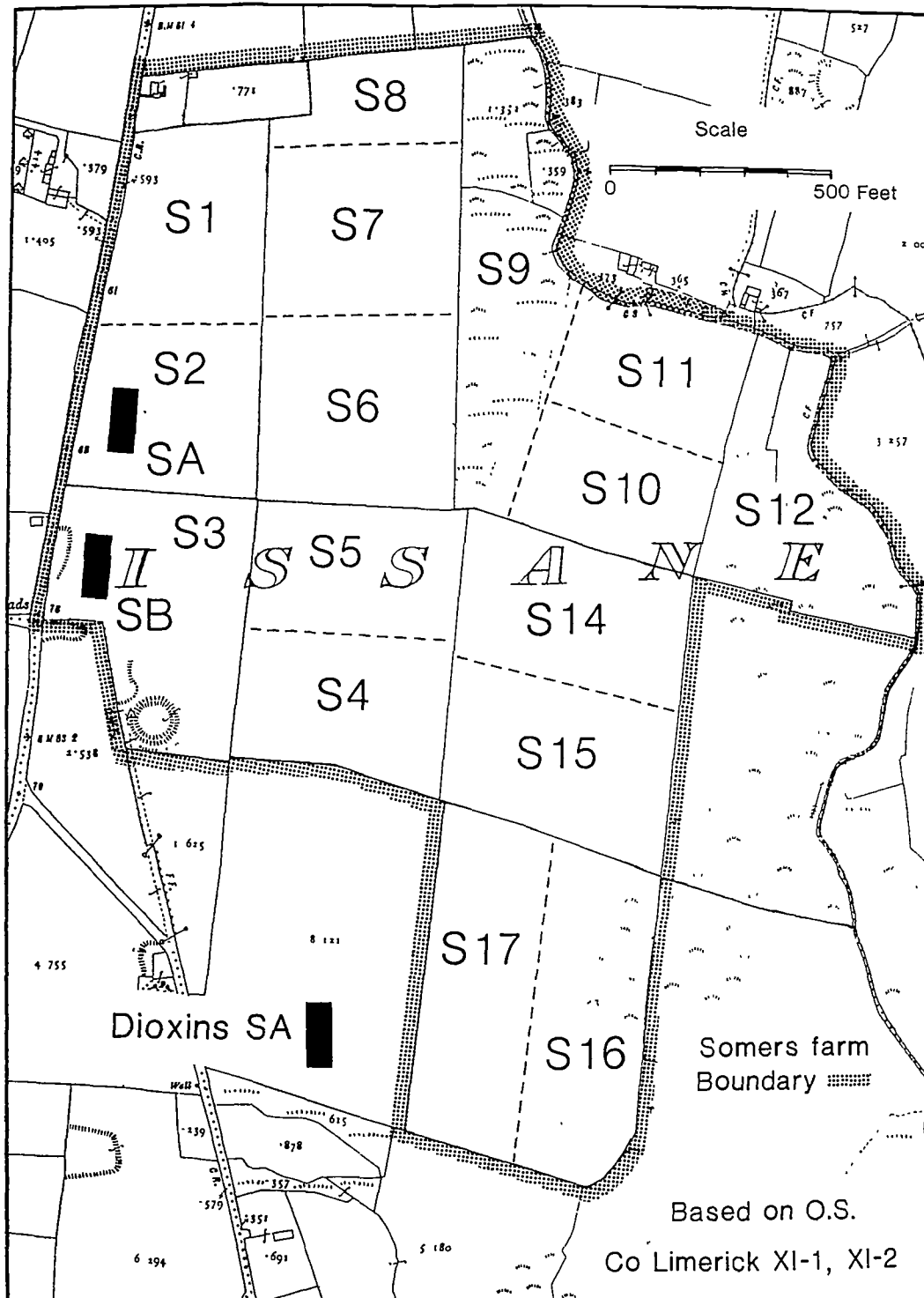


Fig. 8: Soil and herbage sampling areas on the Somers farm.

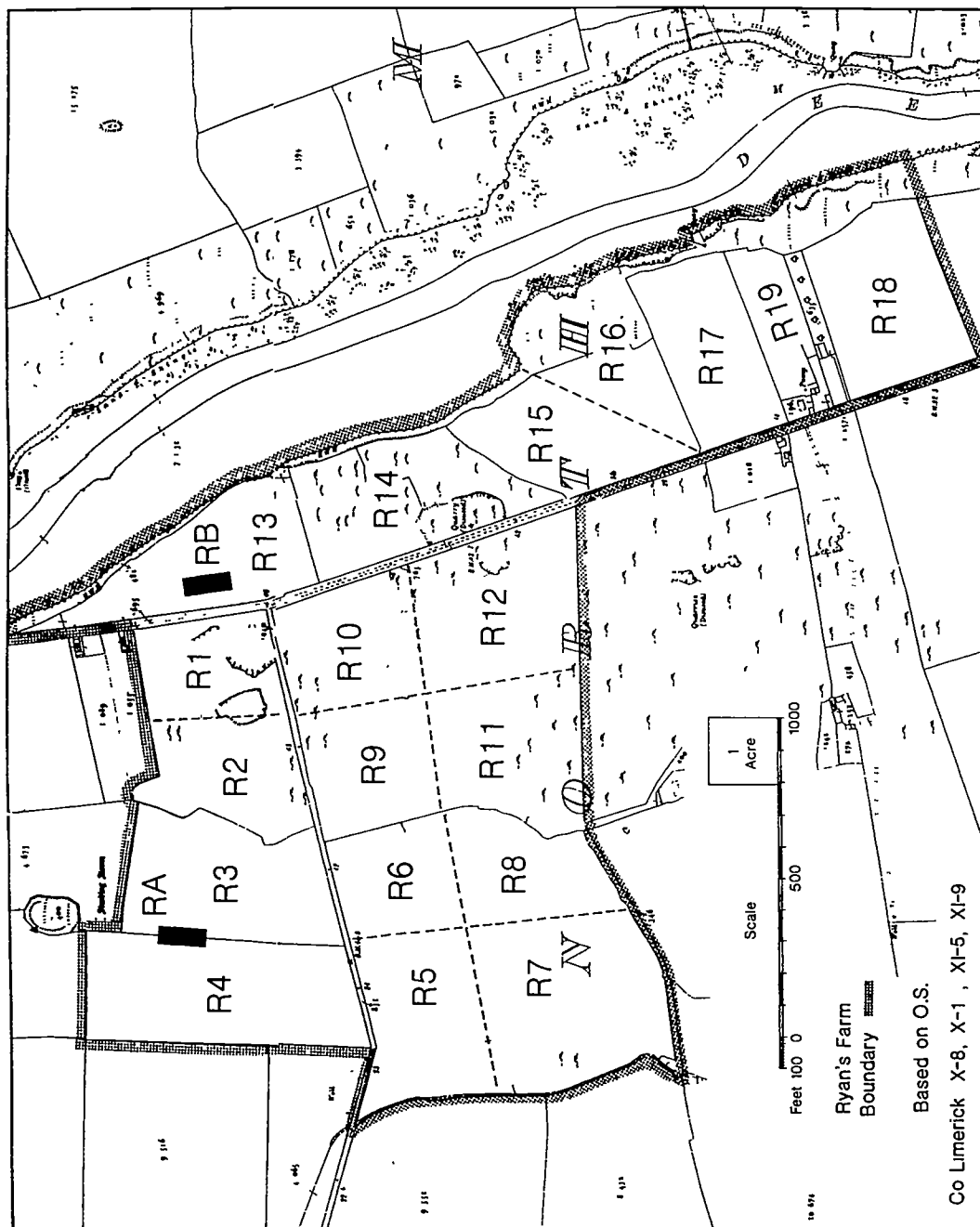


Fig. 9: Soil and herbage sampling areas on the Ryan farm.



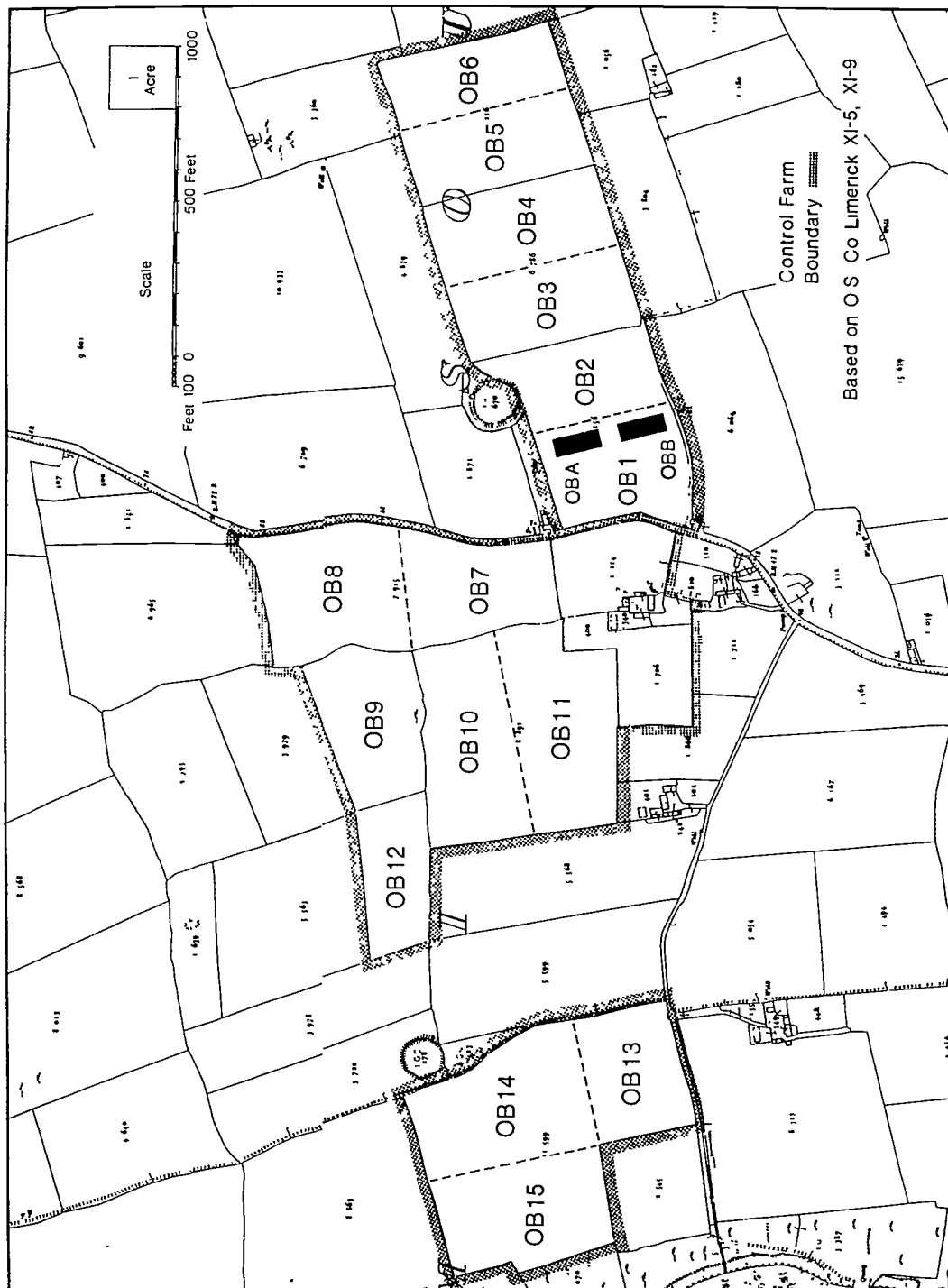


Fig. 10: Soil and herbage sampling areas on the Control farm.

## **CHAPTER 5**

### **HERBAGE ANALYTICAL RESULTS**

#### **5.1 INTRODUCTION**

Both fodder (silage and hay) and herbage samples were taken for analysis. Even under controlled conditions pasture herbage varies in mineral content throughout the year. Fertiliser treatment will obviously affect pasture mineral content, but even in the absence of applied fertiliser, season and stage of growth effects combine to alter mineral composition. The magnitude of such changes varies depending on the element. In a study such as the present one where material is comprised of different herbage species at different stages of growth and from diverse pasture management systems, major element composition may vary by as much as twofold between maximum and minimum values (Fleming and Murphy, 1968). Trace metal composition of herbage can vary even more, especially following contamination of herbage by soil.

##### **5.1.1 Ranges of Elements in Pastures**

At the present time it is known that nineteen elements are needed by plants for healthy growth, whereas twenty five are needed by animals. The following elements are those required by plants:- carbon, hydrogen, oxygen, nitrogen, calcium, potassium, magnesium, phosphorus, sulphur, boron, chlorine, copper, iron, manganese, molybdenum, zinc, cobalt, silicon and sodium. Cobalt is intimately connected with nitrogen fixation in legumes so a case can be made for its inclusion in the list. Silicon is known to be essential for rice, and sodium is essential for plants adapted to saline environments. These two elements though invariably present in normal herbage species do not appear to be essential for their growth.

In the case of animals all the elements listed above are required together with the following - arsenic, chromium, fluorine, iodine, nickel, selenium and vanadium. The ranges of the above elements - with the exception of carbon, hydrogen and oxygen - normally found in Irish pasture herbage are shown in Tables 5.1 (major nutrients) and 5.2 (trace elements). An estimate of requirement for individual nutrients in herbage is also given (Whitehead, 2000). The latter figures only serve as a general guide as animal requirements vary with animal type, age and stage of development.

##### **5.1.2 Seasonal Variation and Stage of Maturity**

Changes in mineral composition of pasture plant will occur over the growing season. The magnitude of those changes will differ with plant species and all the elements will not be affected to the same extent. Management practices will have a major influence on the variation in content, as will factors such as soil temperature, rainfall and fertiliser applications. Stage of maturity will affect mineral components of pasture plants to a similar extent when dry matter production of the growing plant out-strips uptake of minerals. For pasture species these effects have been described in detail by Fleming and Murphy (1968) and by Fleming (1973).

##### **5.1.3 Soil Contamination of Herbage**

It is relatively simple to take an uncontaminated soil sample but it is much more difficult to obtain a soil-free herbage sample. Soil contamination of herbage can result from (1) trampling by grazing animals, particularly under intensive grazing (2) splashing caused by rainfall, (3) deposition following a prolonged dry period.

Degree of contamination by an element will depend not only on the proportion of soil present but also on the ratio of element in soil relative to plant. Certain elements such as Al, Co, Fe, Cr, V, Ti and F have high (100+) soil/plant ratios and use can be made of these to demonstrate the presence/absence of soil.

It is possible to estimate the extent of soil contamination of a pasture herbage by using the apparent content in herbage of elements with high soil/plant ratios. The most suitable element for this purpose is titanium for which a ratio as high as 10,000:1 (Mitchell, 1960) has been demonstrated.

**Table 5.1:** Typical ranges (g kg<sup>-1</sup>) of major elements in non-polluted Irish pasture and recommended animal (cow, pregnant, non-lactating) dietary concentrations (g kg<sup>-1</sup>).

Element	Symbol	Herbage Content (Whitehead)	Typical Concentration	Animal Requirement (Whitehead)
Calcium	Ca	2.0-17.0	6	2.9
Chlorine	Cl	2.0-20.0	3.5	2.0
Magnesium	Mg	0.8-5.0	2	1.6
Nitrogen	N	10.0-50.0	28	19.2
Phosphorus	P	1.0-5.0	4	2.3
Potassium	K	8.0-40.0	25	6.5
Silicon	Si	1.0-2.0	-	-
Sodium	Na	0.1-6.0	2.5	1.0
Sulphur	S	1.5-3.5	3.5	1.6

A dash (-) indicates lack of data

#### 5.1.4 Toxicity

A number of elements necessary for plant and/or animal health may be present in herbage in toxic amounts and thus can cause harm to grazing stock. Similar remarks apply to a number of contaminant elements, that is elements which fulfil no known useful function in plant or animal nutrition. It is not possible to give toxicological data for elements in herbage for a number of reasons including the fact that their toxicities may be enhanced or mitigated by the presence of other elements.

## 5.2 SAMPLING AND ANALYSIS

Grass was sampled close to ground level using an electric shears, taking care not to include soil, between May 9 and 11, 1995. Sampling locations were analogous to those used for soils. Samples from the one enclosure were bulked to comprise a single plot sample. These were dried at 104°C for general analysis and at 40°C for Se, As and Hg analysis. Procedures generally involved strong acid digestion and estimation by flame or electrothermal atomic absorption analysis as appropriate (Appendix 10, Byrne 1979).

## 5.3 HERBAGE - MACRONUTRIENTS

The concentrations of the macronutrients in herbage from the three farms are summarised in Table 5.3. The complete results are presented in Appendix 11.

**Table 5.2:** Typical ranges dietary concentration (mg kg<sup>-1</sup>) of trace elements in non-polluted Irish pastures and recommended (cow, pregnant, non-lactating) dietary concentration.

Element	Symbol	Herbage Content	<sup>2</sup> Typical Concentration	<sup>2</sup> Animal Requirement
Antimony	Sb	0.05-0.3	<sup>1</sup> -	nil
Arsenic	As	0.05-0.3	-	-
Boron	B	1-20	5	nil
Cadmium	Cd	0.01-0.3	-	nil
Chromium	Cr	0.1-0.3	-	-
Cobalt	Co	0.03-0.2	0.1	0.10
Copper	Cu	2-15	-	10
Fluorine	F	0.5-10	9	-
Iodine	I	0.05-0.3	-	0.60
Iron	Fe	20-300	150	50
Lead	Pb	0.5-20	-	nil
Manganese	Mn	20-300	165	40
Mercury	Hg	0.01-0.05	-	nil
Molybdenum	Mo	0.05-2	0.9	-
Nickel	Ni	0.5-3	-	-
Selenium	Se	0.03-0.5	0.05	0.3
Titanium	Ti	1-5	-	nil
Vanadium	V	0.05-0.5	-	-
Zinc	Zn	20-60	37	40

<sup>1</sup>A dash (-) indicates lack of data

<sup>2</sup>Whitehead (2000)

**Table 5.3:** Mean nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), sodium (Na), Calcium (Ca) and sulphur (S) values (g kg<sup>-1</sup>) in the herbage from the Somers, Ryan and Control farms.

Farm	N	P	K	Mg	Na	Ca	S
Somers	31.0	3.8	31.0	1.7	2.4	6.6	2.8
Ryan	32.0	4.1	25.0	2.0	3.0	5.8	3.8
Control	30.0	2.8	24.0	1.6	4.8	4.3	3.0

All the values are within the typical ranges found on grassland farms. The phosphorus and calcium levels on the Control farm are low. Sulphur levels of the herbages, and in particular the nitrogen/sulphur ratio (averaging about 10) are considered normal for the herbage collected from all three farms. However, on the Ryan farm the sulphur levels in the herbage from fields 12-17 and field 19 are elevated (Appendix 11.2). Nitrogen levels are also elevated on these particular samples which suggests a fertiliser effect. This phenomenon is further considered later (5.2).

The herbage sulphur values obtained in 1995 indicate no increase compared with the Aughinish 1979 and Moneypoint 1981 herbage samples. However, this contrasts with the high herbage sulphur levels (5.0 g kg<sup>-1</sup>) reported in 1994 (Analytical Results, Johnstown Castle). It is important to realise in making these comparisons that factors such as time of sampling, stage of growth, cultivar, fertility, climate, soil conditions and management influence the sulphur levels in the herbage. These aspects are discussed in more detail in Sections 5.8-5.10.

#### 5.4 HERBAGE - ESSENTIAL MICRONUTRIENTS

Manganese, copper, molybdenum, selenium, iodine, zinc and boron contents of the herbages are summarised in Table 5.4. The full results are presented in Appendix 12.

**Table 5.4:** Mean manganese (Mn), copper (Cu), molybdenum (Mo), selenium (Se), iodine (I), zinc (Zn) boron (B) and fluorine (F) concentrations (mg kg<sup>-1</sup>) in the herbage from the Somers, Ryan and Control farms

Micronutrient	Somers	Ryan	Control
Mn	72	239	148
Cu	8.9	9.9	8.9
Mo	1.9	2.2	1.0
Se	0.13	0.07	0.04
I	0.19	0.30	0.14
Zn	24	30	27
B	8	7.0	6.5
F	10.6	11.5	5.6

Manganese values in excess of 40 mg kg<sup>-1</sup> probably satisfy animal needs (Redostits et al., 1994). However, one paddock on the Somers farm yielded herbage with slightly lower Mn values. Compared to the other farms, herbage from this farm had lower Mn, and also higher Ca which depresses Mn uptake by the plant and also absorption by the animal (Cowgill et al., 1980).

Copper, molybdenum and sulphur are considered together because of their interrelationships in animal nutrition (5.9, later). The copper values can be taken in general to be satisfactory as the mean values for the three farms are just slightly below the suggested requirement for animals, *i.e.* 10 mg kg<sup>-1</sup>. Some samples on the Somers farm are in a low category. This reflects the higher soil pH on the farm (Table 4.4). Approximately half of the herbage samples from the Somers and Ryan farms have slightly elevated molybdenum values. These are such that they are unlikely to cause copper problems in animals. The lower molybdenum values on the Control farm may be due in part to the lower soil pH values.

The selenium levels in the herbage on all three farms are low. Almost half of the samples from the Somers farm had low selenium. However, there were also some high values. These higher values were for samples taken from the low lying area. The assignation of sufficiency levels, especially for selenium, is discussed in Section 5.10.

Iodine values on the Somers and Control farm fall below accepted standards (Whitehead, 2000) but are

typical for uncontaminated Irish herbage (McGrath and Fleming, 1988). The mean value for the Ryan farm is high because some of the herbage samples were soil contaminated.

The zinc values on the Ryan and Control farm are low but within the typical range. However, half of the herbage samples from the Somers farm were low in zinc. The boron levels in the herbage were satisfactory on the Somers, Ryan and Control farms. The fluorine levels in the herbage from Somers and Ryan farms are somewhat elevated relative to those from the Control farm and reflect soil contamination of the herbage on these farms.

In summary, micronutrient levels in the herbage on the three farms are typical in an Irish context. However, it should be noted that selenium, copper, iodine and zinc levels are lower than those considered adequate for the nutrition of animals (Whitehead, 2000; ARC, 1990).

## 5.5 HERBAGE - HEAVY METALS

The mean heavy metal values for the herbage samples are given in Table 5.5. The full results are given in Appendix 13. Iron has been included with this group. In general, the values fall within the usual range for Irish herbage samples. The high titanium values demonstrate a degree of contamination by soil in the case of the Somers and Ryan herbages compared to those of the Control. Elevated iron, aluminium, vanadium values in particular are associated with high titanium values and support this conclusion.

**Table 5.5:** Mean arsenic (As), mercury (Hg), lead (Pb), chromium (Cr), cadmium (Cd), nickel (Ni), iron (Fe), titanium (Ti), aluminium (Al) and vanadium (V) concentrations (mg kg<sup>-1</sup>) of herbage samples from the Somers, Ryan and Control Farms

Element	Somers	Ryan	Control
As	0.54	0.58	0.19
Hg	0.021	0.02	0.022
Pb	1.23	2.72	1.58
Cr	0.67	0.96	0.48
Cd	0.09	0.16	0.08
Ni	1.7	2.93	2.33
Fe	293	434	158
Ti	33.3	71.4	21.2
Al	376	572	209
V	1.70	3.77	0.79

## 5.6 SUMMARY

In summary, the composition of herbage from all three farms was unexceptional. Where herbage tended to contain high levels of some elements, contamination was clearly a factor. This is reflected in the raising of contents of major elements like iron and aluminum but also of trace elements and heavy metals in grass. This normally happens, with an element where its level in soil considerably exceeds its level in plant. Soil ingestion constitutes a mixed blessing being an entry route for pollutants and substances that interfere with nutrient absorption by animals but is also a means of supply of elements that are essential to

animals, particular cobalt and iodine. What can be said is that soil ingestion by animals was clearly a feature Somers and Ryan farms in May 1995. Against this complex background no evidence was obtained to indicate aerial contamination of herbage by any individual element that could not be explained by soil contamination.

Herbage grown on the soil with elevated selenium was also higher in the element. A number of herbage samples had low manganese contents. This was particularly the case on the Somers farm and was attributed to the higher pH of soils on this farm.

## 5.7 MISCELLANEOUS BIOLOGICAL SAMPLES

Two samples were taken on March 1995 from the Ryan farm. They comprised (a) an aquatic plant - taken from stream and (b) an "algal mat" - taken from a water trough. The analytical results are recorded in Appendix 14.

*Macronutrients:* The calcium values were high in both samples, (126 and 38 g kg<sup>-1</sup> for the aquatic plant and algal mat, respectively). Sulphur values were elevated in both samples when compared to "normal" herbage values. However, comparative information on sulphur content of these species is not available but the values are similar to those reported for some broadleaved plants. The calcium content of the aquatic plant especially was much higher than contents reported for more familiar plant species and may indicate the presence of non-plant material.

*Micronutrients and heavy metals:* The high titanium values in the two samples suggest that both are contaminated with soil or sediment. The elevated iron and aluminium values would support this view.

## 5.8 SULPHUR - INTRODUCTION

During the course of this investigation considerable attention has been devoted to the role that sulphur emission could have in raising the sulphur content of herbage and thus influencing the nutrition of animals - particularly through reducing availability of copper and selenium. The perception among some parties that herbage sulphur was in fact elevated in the Askeaton area was given substance by a sampling conducted in 1994 on 14 farms surrounding the Somers farm. Analyses of herbage gave a mean value of 5.0 g kg<sup>-1</sup> for herbage sulphur in that investigation. In this discussion three aspects are considered (i) factors that influence herbage S, (ii) normal S levels in Ireland, (iii) analytical aspects.

### 5.8.1 Factors Influencing Herbage Sulphur

Sulphur content of herbage is influenced by many factors including stage of growth, and by plant, soil and climatic factors as well as by the amount of S available from soil and atmospheric sources. Since both sulphur and nitrogen are components of plant proteins amounts of both elements in the plant will tend to increase or decrease in parallel. Sulphur levels in herbage are generally within the range 2.7-6.7 g kg<sup>-1</sup> (Whitehead, 2000). In recent years considerable attention in Ireland and elsewhere is directed to ensuring a sufficiency of sulphur for optimum herbage growth and quality. This is largely because atmospheric levels of S have been reducing over the last 20 years in Western Europe and also because superphosphate (which can contain more S than P) is now little used as a fertiliser. Atmospheric inputs to agricultural crops in the UK are now considered to be so low as to require sulphur fertiliser inputs (Campbell and Smith, 1996). As much as 30% of Irish grassland is believed to receive sulphur in amounts that are insufficient for optimum growth (Murphy and Boggan, 1988). Sulphur is now added to many nitrogenous fertilisers although maybe not yet in amounts sufficient to ensure a balance of S and N.

Since many factors influence S level in plants, herbage is considered to be a very poor indicator of atmospheric S levels. However, herbage sulphur has a use, under controlled circumstances employing uniform swards in pots, to determine sulphur gradients with the objective of pinpointing an emission source. The concern here is not that sulphur was being released into the atmosphere but rather than it might be influencing herbage sulphur levels. Even then a high level of herbage sulphur will have limited impact. Excess dietary sulphur does influence copper availability to the animal but less so where molybdenum is not in excess. Selenium absorption and the complex interaction with sulphur (Ryssen *et al.*, 1998) is still not clearly understood. Also, in intensive agriculture supplementation of feed with copper and other minerals is an economic and efficient way to ensure an adequate level of nutrition (Rogers and Gately, 1998).

### **5.8.2 Normal Herbage Sulphur Levels**

Data available at Teagasc, Johnstown Castle was compiled with a view to determining whether there has been any change in herbage S nationwide over the last 20 years and whether there was any evidence of a departure from the norm in the Askeaton area. Information sources included earlier baseline studies for (a) Moneypoint and Aughinish, (b) for a number of mining developments, (c) a North Wexford farm and (d) for a National Farm Profile compilation (Table 5.6). Recent Askeaton sources included (a) the sampling of 1994 which produced high S values, (b) analyses conducted on the Ryan, Somers and Control Farm 1995, (c) the monitoring program of 1995-1998 (5.12) and (d) a set of data from 12 locations (5 farms), from the farms participating in the retrospective survey and which were on record as having been received for analysis at Johnstown Castle between 1990 and 1994 (Table 5.7). The last included samples from Index Farm 1 and from Farms RS 9, 22, 24 and 31. There was some evidence for high S in some surveys. It is noted that Nutrient Profile Farms, which had high outputs, naturally had high N and S usage. However, one additional group these set of 14 from the Askeaton area sampled in June 1994, did have anomalously high S values although N levels were moderate (Table 5.8). It was not only that they included some high S samples - all herbage populations did this. It was the general level of S in the samples. These samples had been obtained from grazed paddocks on farms adjacent to the Somers farm in June 1994 about the time that the animal health problem was first drawn to the attention of Teagasc. Sulphur values were similar in magnitude to those reported for areas where severe eupraemia has been found (Leach and Thornton, 1986).

### **5.8.3 Sulphur Analytical Aspects**

Samples that displayed high sulphur values when analysed in 1994 were subjected to re-analysis in 1995 (Table 5.8). It can be seen that values were now more normal even though S/N ratio was slightly higher than normal. It is possible to speculate on the reason for this - soil contamination of the 1994 samples, incorrect analytical procedures. The quantification of sulphur, as sulphate, involved measurement by nephelometry of barium sulphate in suspension. A characteristic of these 1994 soils was their visibly high degree of contamination with soil. It would be reasonable to assume that soil and especially soil with a high content of fine particles, such as could be expected in mid-summer (McGrath *et al.*, 1982) could interfere with sulphur estimation (since the process depends on the formation of a colloidal suspension of barium sulphate) although we can find no mention of this in the literature. Soil contamination also helps to explain the variability of the results that were experienced on repeat analysis. (To update the method would mean investment in expensive equipment). The performance of the laboratory has been backchecked as to how it behaved with S analysis of reference materials over the period 1995-1997 in an international analytical programme with more than 50 participating laboratories. The mean departure of the Johnstown Laboratory from the norm was 9.3%. There was no bias, as the departure from the mean was less than 1% when the direction of the error was considered. Thus, having regard to the fact that the original high S values could not be substantiated and the unsatisfactory nature of the samples (they were seriously contaminated by soil) must be regarded as unsafe.



**Table 5.6:** Sulphur (S) levels ( $\text{g kg}^{-1}$ ) in surveys of grazed pastures from Johnstown Castle data

Survey	Date survey conducted	Number (n)	N	S	N/S
(a) Moneypoint	<sup>1</sup> 1981	216	29	3.0	10.1
	<sup>1</sup> 1982 (July/Aug)	49	31	3.0	10.3
	<sup>2</sup> 1993 (Resampling)	52	30	2.9	10.8
(b) Aughinish	<sup>3</sup> 1979	113	26	3.3	8.4
(c) Galmoy	<sup>4</sup> 1993 (April/May)	154	39	3.6	10.9
	1993 (Sept/Oct)	155	29	3.7	8.2
(d) Lisheen	<sup>4</sup> 1991 (May/June)	181	30	3.3	9.4
	1991 (October)	185	32	3.4	9.2
(e) N. Wexford farm	<sup>4</sup> 1990 (June)	36	31	3.7	8.8
	1990 (October)	36	26	3.1	8.4
(d) Farm Nutrient Profile Survey <sup>1</sup>	<sup>5</sup> 1991-1992				
	March/June	57	39	4.1	9.7
	July/August	19	37	4.3	8.8
	Sept/Oct	72	40	4.3	9.4

<sup>1</sup>Fleming and Parle, 1984<sup>2</sup>Coulter et al. 1994<sup>3</sup>Fleming and Parle, 1983<sup>4</sup>Parle, personal communication, 1997<sup>5</sup>Gately and Blagden, 1993**Table 5.7:** Recent analyses of sulphur ( $\text{g kg}^{-1}$ ) in herbage, mainly from the Askeaton area

Survey	Year	n	N	S	N/S
(a) Adjacent to Somers farm	July 1994	14	29.0	5.0	5.9
(b) Askeaton Somers Ryan Control	May 1995	16	31.4	2.8	11.0
		19	31.6	3.8	8.3
		15	29.5	2.9	10.2
(c) Monitoring Somers Ryan	Nov. 1995				
	To	72	37.5	3.6	10.5
	Feb 1998	69	36.9	3.8	9.9
(d) Retrospective 1990-1994	Askeaton 1990-1994	12	28.9	3.6	8.6

**Table 5.8:** Mean values of nitrogen and sulphur ( $\text{g kg}^{-1}$ ) in herbage samples from Askeaton, July 1994

Survey	Year	n	N	S	N/S
1 <sup>st</sup> Analysis	1994	14	29.0	5.0	5.8
Reanalysis	1995	13*	-	3.4	8.5

\*Insufficient material for re-analysis of one sample

## 5.9 SULPHUR, COPPER, MOLYBDENUM

Sulphur deficiency in grassland in Ireland is associated with light-textured soil low in organic matter content. Herbage production can be affected, as can the quality. Levels of less than  $2.0 \text{ g kg}^{-1}$  are considered to be undesirable especially if the ratio of nitrogen to sulphur in the plant is in excess of fifteen.

Low levels of copper do not normally affect grass production in Ireland, particularly on mineral soils, but deficiencies can occur in cereals and root crops.

Molybdenum deficiency in crops is rare in Ireland except, perhaps, in cauliflower.

The molybdenum requirements of animals are extremely low and can be met by most natural dietary ingredients. Animal disorders arise from a shortage of copper with the young bovine being particularly susceptible. When molybdenum in herbage is in excess, it has the effect of reducing the availability of copper from pasture to the grazing animal. If sulphur levels are also high, the effect can be exacerbated (Suttle, 1978). Levels  $>3 \text{ g kg}^{-1}$  must be considered suspect in this regard.

Pasture species vary in copper content. This will be influenced by the copper content of the soil, pH of the soil, stage of maturity of pasture, season and management procedures such as fertiliser usage - particularly nitrogen applications. Levels of copper of  $>10 \text{ mg kg}^{-1}$  in herbage are desirable for cattle but are rarely attainable in pure ryegrass swards. Old pasture containing clover and plant species will usually have higher levels of copper than the pure ryegrass pastures.

The sources of the Irish high-molybdenum soils are Carboniferous black shales and Calp limestones. The main areas with such soil parent materials are found in the Midlands, Co. Limerick and sporadically eastward from there to Clonmel. Other small areas are scattered throughout the country. An elevated soil pH greatly increases the uptake of molybdenum by plants. The magnitude of the increase varies with species - clover contents being higher than grasses, whereas with grasses Cocksfoot (*Dactylis glomerata*) and Yorkshire fog (*Holcus lanatus*) will absorb more molybdenum than do the ryegrasses. Molybdenum uptake can also be influenced by season, which is mainly a reflection of the moisture status of the soil. Following wet periods there can be up to a fivefold increase in molybdenum content in pasture species.

Elements such as zinc, cadmium and iron can also depress copper absorption by the animal and can reduce plasma copper concentrations when ingested at high dietary levels. Soil ingestion, particularly at high stocking rates and at the end of the grazing season, when soil moisture is high, can be major source of metal intake, especially in the case of iron.

## 5.10 MONITORING OF HERBAGE FROM RYAN AND SOMERS FARMS

- November 1995-February 1997

Herbage was sampled to ground level on 4 pre-selected paddocks on both Ryan and Somers farms. Sampling was conducted at 4-8 weekly intervals between November 1995 and February 1998. Samples were analysed for nitrogen, sulphur, selenium and molybdenum. Mean results of these analyses are shown in Table 5.9 and variation over time in Figs 11 (S), 12 (N), 13 (Se) and 14 (Mo).

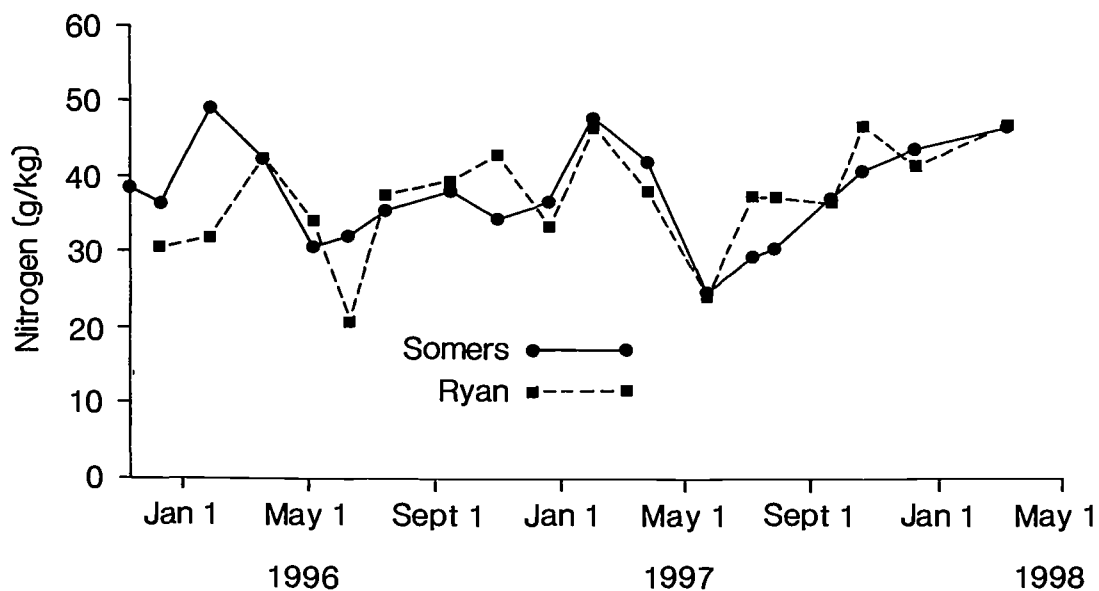
**Table 5.9:** Mean herbage S ( $\text{g kg}^{-1}$ ), N ( $\text{g kg}^{-1}$ ), Se ( $\text{mg kg}^{-1}$ ) and Mo ( $\text{mg kg}^{-1}$ ) on Somers and Ryan farms, 1995-1998.

	Somers				Ryan			
	S	N	Se	Mo	S	N	Se	Mo
Mean	3.6	37.6	0.14	1.52	3.8	30.9	.07	1.04
Max	5.20	49.0	0.28	2.34	5.20	52.0	0.15	2.78
Min	2.40	24.6	0.07	0.97	2.40	23.7	0.03	0.52

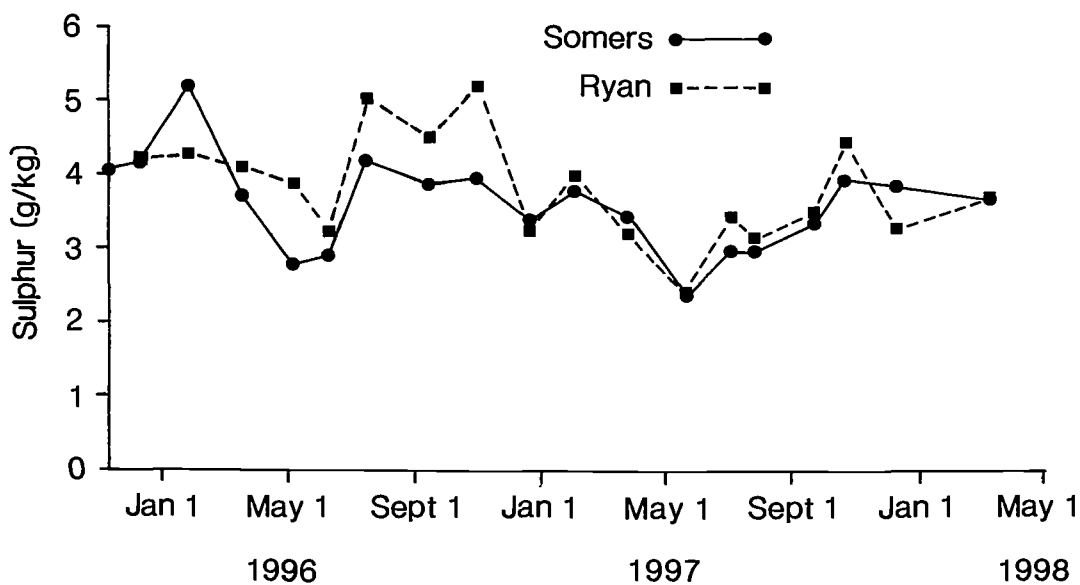
**Table 5.10:** Frequency distribution of selenium ( $\text{mg kg}^{-1}$ ) in Irish pastures 1986-1993

Range ( $\text{mg/kg}$ )	0-0.05	0.05-0.07	0.07-0.10	0.10-0.15	0.15-0.5
%	26.4	32.9	18.0	12.9	9.7

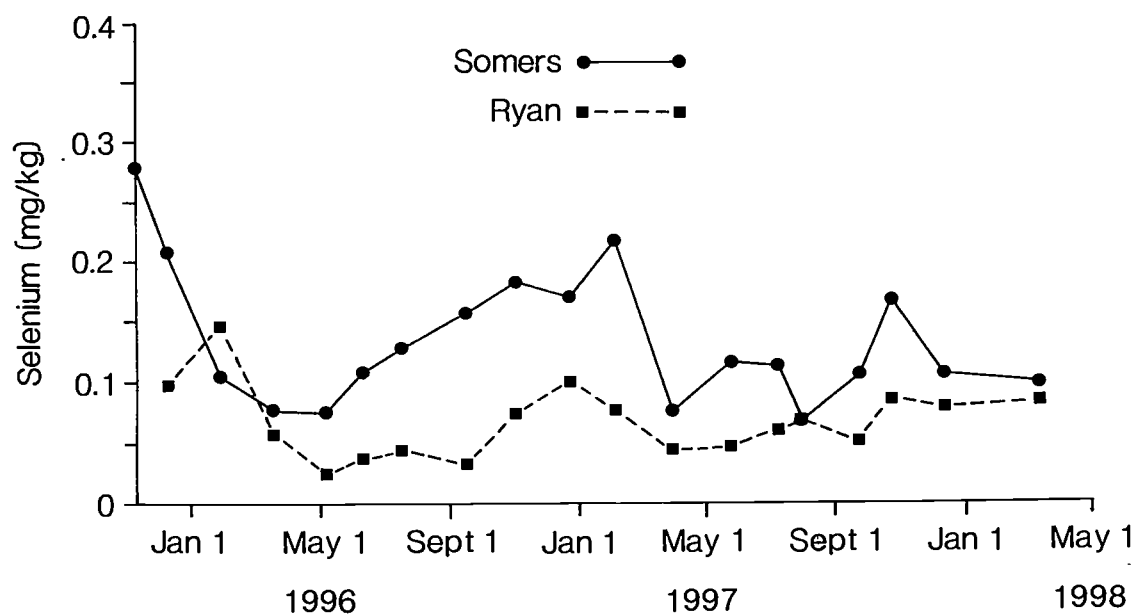
<sup>†</sup>Samples received for analysis at Johnstown Castle (P. Parle, personal communication, 1995)



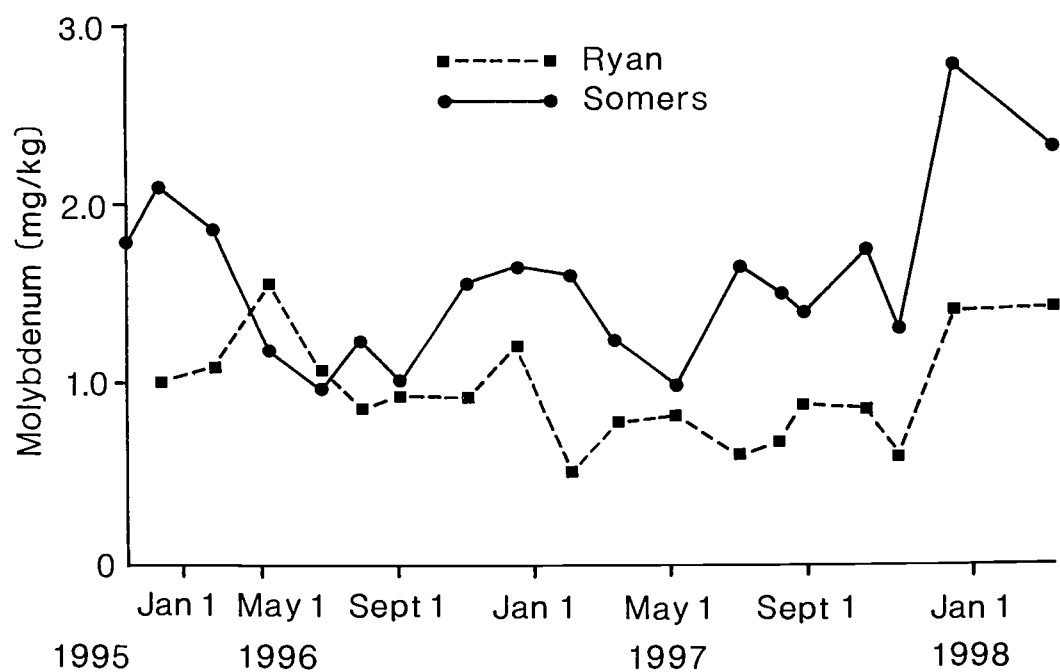
**Figure 11:** Variation of nitrogen content of herbage.



**Figure 12:** Variation of sulphur content of herbage.



**Figure 13:** Variation of selenium content of herbage.



**Figure 14:** Variation of molybdenum content of herbage.

*Sulphur and Nitrogen.* Sulphur content of herbage was generally high, averaging about 3.5 g kg<sup>-1</sup> (Table 5.9). There was little difference on average between mean S levels on Ryan and Somers farms. Individual S values varied with N. However, herbage N and S, for samples taken on the same occasion from different fields on the same farm varied by as much as two-fold. Winter values tended to be higher than summer values on average (Fig. 12). In general the range of values and mean values over time were similar to those encountered in surveys (Table 5.6). There is no evidence of an excess of sulphur in herbage on either farm between November 1995 and February 1998.

Mean sulphur levels (with SD) in the four individual sampled sites were 3.86 (0.77), 3.64 (0.73), 3.68 (0.86) and 3.29 (0.99) g kg<sup>-1</sup> on the Somers farm and 4.04 (0.90), 3.66 (0.75), 3.52 (0.74), 3.97 (0.86) mg kg<sup>-1</sup> on the Ryan Farm. No statistically significant difference between any site could be demonstrated. On the Somers farm higher values were associated with proximity to the roadway – on the Ryan Farm with proximity to the mud flats on the River Deel which bordered the eastern side of the farm.

*Selenium:* Selenium values were generally higher on Somers than on the Ryan farm (Fig. 13 and Table 5.9) as anticipated. Replicate values for either farm at the one time varied considerably - by a factor of as much as five-fold. This finding does not encourage the belief that a single selenium determination for herbage in a paddock can accurately reflect the quantity of selenium available to grazing animals on a farm. In their baseline survey of the Aughinish area, Rogers and Poole (1984) highlighted the variation in herbage selenium within farms and between seasons. Winter values were higher than Summer values (Fig. 13) which has been previously noted (Haygarth et al., 1993). Regression analysis showed that increase in herbage selenium were unrelated to increases in herbage sulphur. A similar situation has been reported for atmospheric levels of these elements in areas suffering from low levels of pollution: conversely a highly significant relationship between the two elements occurred where pollution levels were high and sources numerous (Eldred, 1997). Much of plant sulphur (Whitehead, 2000) and plant selenium (Haygarth, et al. 1993) is derived from atmospheric sources. The pattern of the relationship in Askeaton was suggestive of a comparatively small number of weak local sources for both elements for example, households and small industries rather than large industries.

Mean selenium levels (with SD) on the four individual sampled sites were 0.079 (0.044), 0.189 (0.076), 0.162 (0.099), and 0.100 (0.093) mg kg<sup>-1</sup> on the Somers farm and 0.066 (0.038), 0.067 (0.045), 0.066 (0.027) and 0.070 (0.035) mg kg<sup>-1</sup> on the Ryan farm. Difference between some of the Somers sites were statistically significant ( $P \leq 0.05$ ) with higher levels on paddocks 7 and 12 that had been found to have higher soil Se (Appendix 5.1). As adjacent parts of the farm had higher Se, yet higher increases in herbage selenium in unmonitored parts of the farm can be assumed. Levels of selenium on all parts of the Ryan farm were generally low with means of 0.06-0.07 mg kg<sup>-1</sup> over the period. Levels during the grazing season were generally lower (Fig. 13) generally ranging from 0.04-0.06 mg kg<sup>-1</sup>. The values though decidedly low are far from unique in the Irish (Table 5.10) and Scottish (Price, 1989) contexts. Price has argued that values of 0.03-0.05 mg kg<sup>-1</sup> selenium in herbage does not necessarily indicate a resultant biochemical (blood enzyme) deficiency not to mention a clinical deficiency.

*Molybdenum:* Molybdenum values again varied (Fig. 14) to an extent similar to selenium. On both Ryan and Somers farms Mo values were never so high as to present a serious risk of reducing copper availability to a dangerous extent.

## 5.11 OTHER MONITORING

Selected data are given for level of copper, zinc and molybdenum for Ryan and Somers Farms (Table 5.10 and 5.11) for dates in 1996 and for Abbotstown farm in 1996 (Table 5.12 and 5.13).

**Table 5.11:** Seasonal variation of trace elements in herbage paddocks (4) on Ryan and Somers farms 1996

Date	Somers			Ryan		
	Cu	Zn	Mo	Cu	Zn	Mo
	mg kg <sup>-1</sup>			mg kg <sup>-1</sup>		
March 20	8.2	23	1.2	10.5	48	1.8
May 8	7.4	20	1.2	9.6	26	1.1
June 11	7.3	22	1.9	7.5	25	1.2
July 16	8.9	27	1.6	8.7	35	1.2
Sept 13	9.9	24	1.7	9.7	30	0.9
Oct 30	9.5	28	2.0	11.5	32	1.4

**Table 5.12:** Composition of September/October 1996 samples from Askeaton and Abbotstown farms

Date	N	S	N/S	Se	Cu	Zn	Mo
	g kg <sup>-1</sup>			mg kg <sup>-1</sup>			
September							
Somers (4)	39	3.9	10.0	0.16	9.9	24	1.7
Ryan (4)	39	4.5	9.0	0.03	9.7	28	0.9
Abbotstown (10)	32	4.4	7.4	0.65	13.7	50	5.8
October							
Somer (4)	36	4.2	8.5	0.18	9.5	30	2.0
Ryan (4)	43	5.2	8.2	0.07	11.5	32	1.4
Abbotstown (10)	46	3.8	8.3	0.60	21.8	53	3.2

**Table 5.13:** Abbotstown herbage (10 paddocks) 1996

Date	S	N	Se	Cu	Zn	Mo
	g kg <sup>-1</sup>		mg kg <sup>-1</sup>			
September	4.4	32.0	0.65	13.7	50	3.8
October	4.6	38.0	0.60	21.8	53	3.2

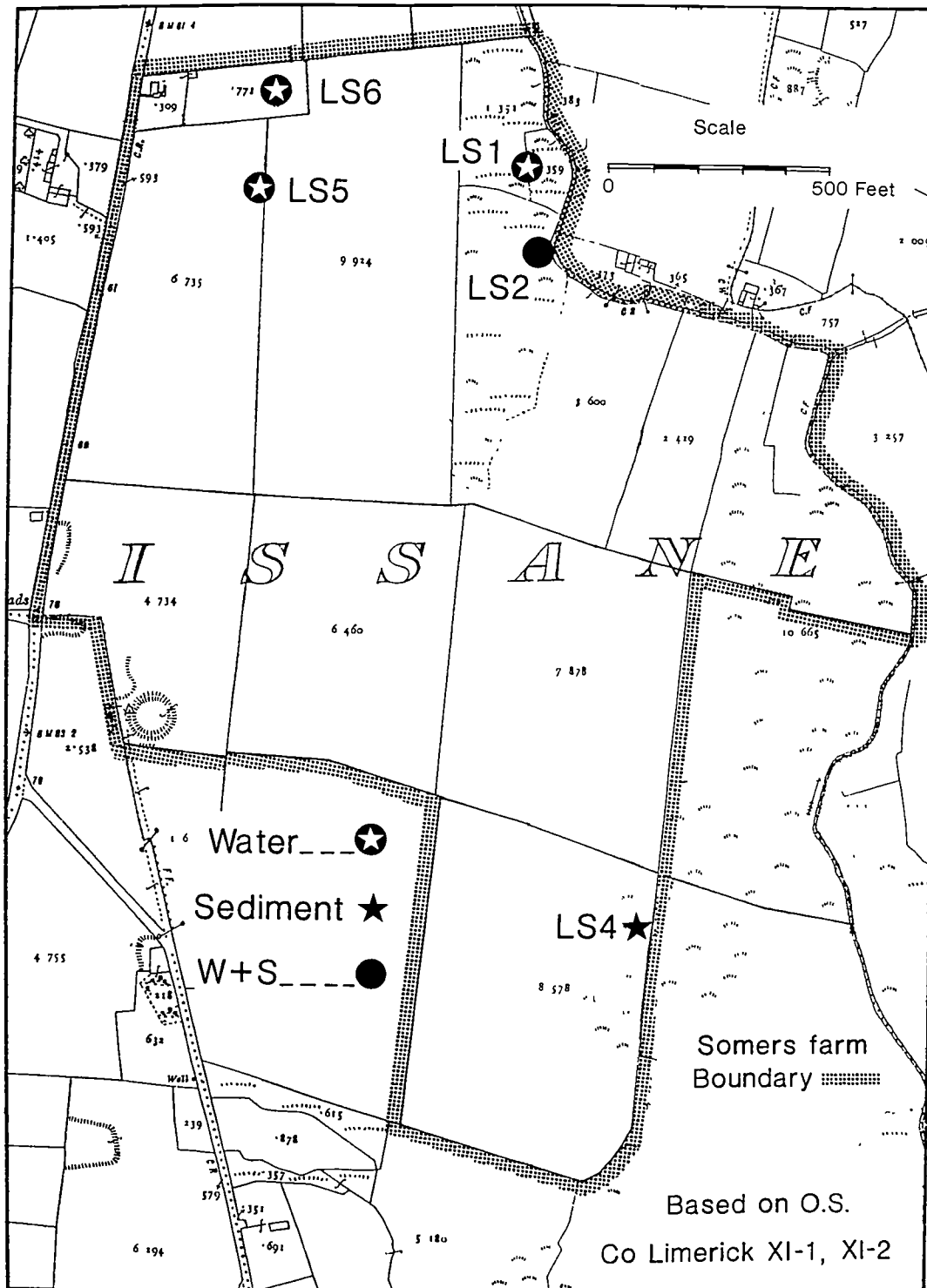


Fig. 15: Sources of the sediment and miscellaneous samples on the Somers farm



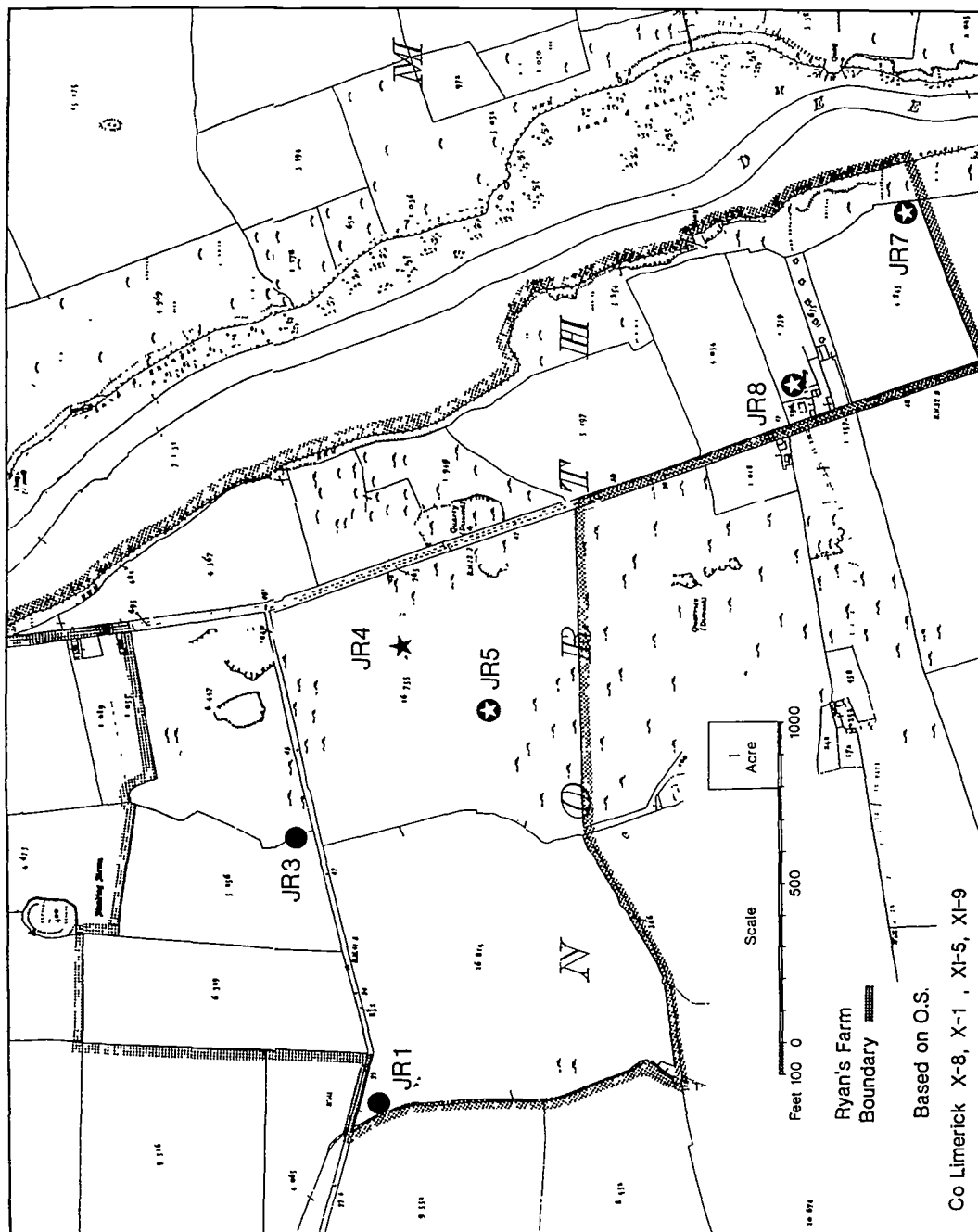


Fig. 16: Sources of the sediment and miscellaneous samples on the Ryan farm.

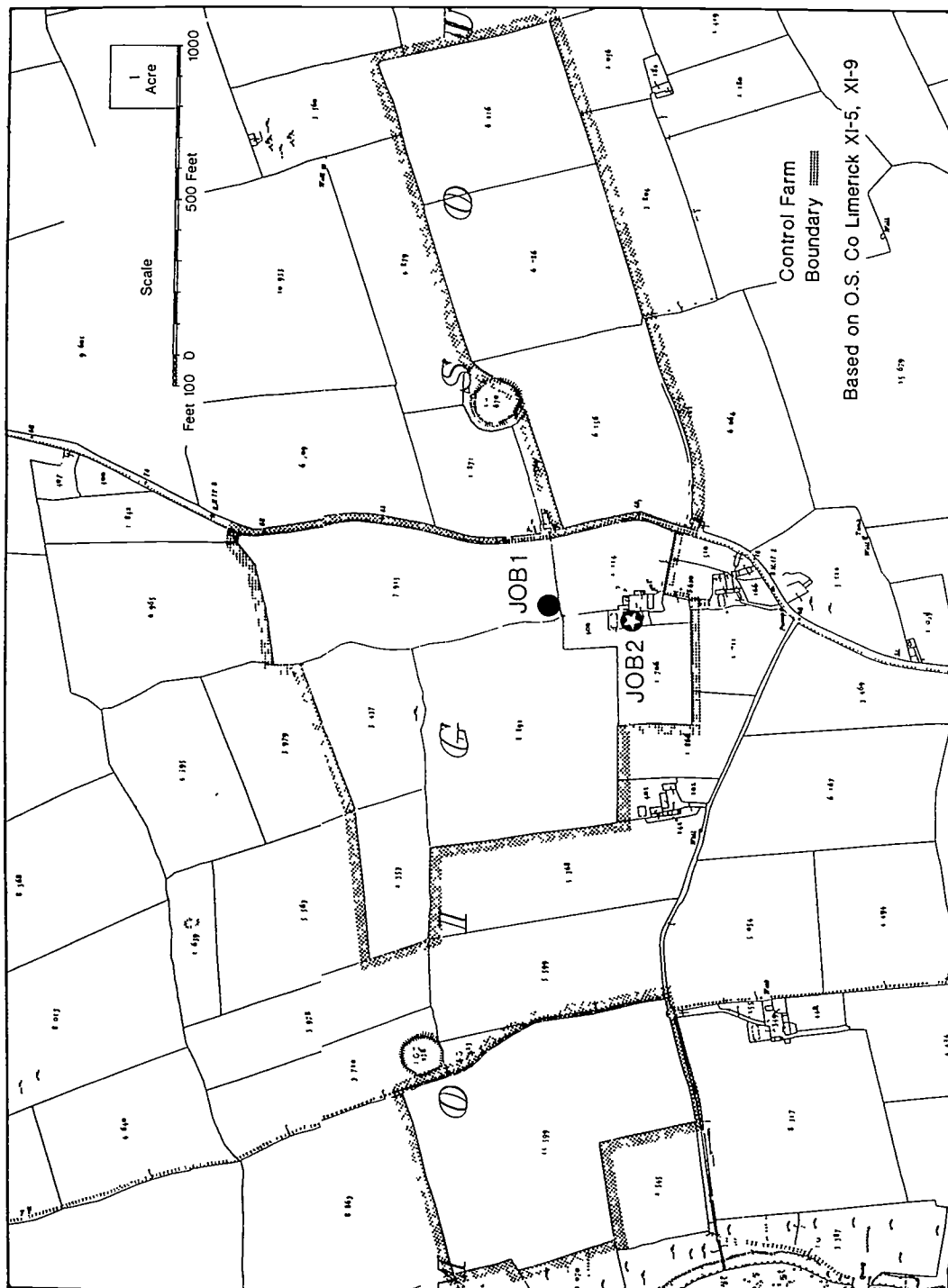


Fig. 17: Sources of the sediment and miscellaneous samples on the Control farm.

## CHAPTER 6

### WATER, MINERAL MIX, CONCENTRATE AND FORAGE ANALYSIS

#### 6 WATER

Analytical methods for all water samples followed procedures outlined in Standard Methods of Analysis of the American Public Health Society, 1992).

A number of water samples were taken for analysis in March 1995. The sampling points for these and other materials sampled at this time are shown in Figs 15, 16 and 17 and are summarised in Table 6.1.

**Table 6.1:** Location of water-related samples

Figure	Sample No.	Nature - Source	Discussed (Section)
15	LS1	Water - drain	6.2
	LS2	Water-stream	6.2
	LS2	Sediment - stream	4.11
	LS4	Sediment - drain	4.11
	LS5	Water - trough	6.3
	LS6	Water - tap	6.11
16	JR1	Water - stream	6.2
	JR1	Sediment - stream	4.11
	JR1	Aquatic plot - stream	5.6
	JR3	Water - trough	6.3
	JR3	Sediment - trough	4.11
	JR4	Sediment - trough	4.11
	JR5	Water - trough	6.3
	JR5	Algal met - trough	5.6
	JR7	Water - trough	6.3
	JR8	Water - tap	6.1
17	JOB 1	Water - trough	6.3
	JOB 1	Sediment - trough	4.11
	JOB 2	Water - tap	6.1

#### 6.1 TAP WATER

Tap water (outside locations) results for the Somers's, Ryan and Control farms are presented in Appendix 15.1. Results were compared with EU Maximum Allowable Concentration (MAC) figures given in Drinking Water Standard, SI No. 81 of 1988.

*Somers Farm:-* Total and faecal coliforms values were above the EU MAC value. This would normally render the sample unsuitable for drinking, and treatment to remove the coliforms is recommended. There was 18 mg l<sup>-1</sup> of suspended solids in the sample which is also outside the MAC value. It was assumed that the contamination came from the black plastic tube which was connected to the tap and trailed along the ground.

*Ryan Farm.-* All analyses are within the MAC values.

*Control Farm*:- Potassium is higher than the MAC value. The coliforms are outside the MAC value. The possible cause of the contamination appears to be a plastic tube, very similar to the situation on the Somers farm noted above.

The water from the taps at the Somers and Control farm were resampled in August, 1995. The plastic tubes were removed from the taps and the taps were flamed prior to taking the samples. The results are as follows:

**Table 6.2:** Repeat analysis of tap water.

	<b>Somers</b>	<b>Control</b>
Total Coliforms (100 ml <sup>-1</sup> )	32	40
Faecal Coliforms (100 ml <sup>-1</sup> )	0	32
Total Potassium (mg l <sup>-1</sup> )	2.5	25.4

These repeats suggest that there is some bacterial contamination of the tap water on both farms. The reason for the elevated potassium on the Control farm is not known.

## **6.2 STREAM WATER AND DRAIN**

Analytical results for the streams running through Somers and Ryan farms, together with a sample from the drain on Somers farm are presented in Appendix 15.2. The results are compared with EU MAC values for surface water SI. No. 294 of 1988. The drain water on Somers farm is slightly above the MAC value for BOD.

The chemical properties for stream and drain waters are within the MAC values for surface water. There are total and faecal coliforms present which is indicative of bacterial contamination.

## **6.3 TROUGH WATER**

Samples were taken from the water troughs on the Somers, Ryan and Control farms. On the Ryan farm three animal drinking troughs were sampled. Results are presented in Appendix 15.3 and compared with EU MAC values for drinking water (SI No. 81 of 1988). Samples in polythene containers, were analysed immediately on return to the laboratory. Water for coliform and BOD assay was collected in sterile (polythene) containers.

The results for all samples were within MAC values with the following exception. The coliforms in the samples from the Somers farm and trough No. 2 from the Ryan farm exceed the MAC values for drinking water. There was a low level of BOD present in all troughs sampled. Potassium is higher than the limit on the Control sample and there are suspended solids in samples from the Ryan and Control drinking troughs. Trough No. 3 on the Ryan farm is just outside the MAC value for manganese.

## **6.4 CONCENTRATES AND MINERAL MIXTURES**

The following concentrate feed and mineral mixtures samples were taken

- Somers Farm** - Concentrates - MC Super Cow, Beef nuts and Crunchy Calf Ca.  
Mineral mixture - Preference Products Dairy & Suckler (pre calving) mix and Calf/Beefgro mix.
- Ryan Farm** - Concentrates - MC Special Bb.  
Mineral mixtures - Preference Products Dairy & Suckler (precalving) mix.

### **6.4.1 Results**

The analytical data obtained for these products together with the manufactures certified values are given in Appendix 16. The values obtained fall within the acceptable parameters for these products, except for the cadmium which is slightly elevated in the concentrates and is elevated in the Calf/Beef mineral mixture and particularly so in the Dairy Mix (Appendix 16.5) which had a cadmium content of 1.80 mg kg<sup>-1</sup>. Use of this material will however have little effect on the cadmium intake of the animal.

In summary, other than bacterial contamination of some of the tap and stream water supplies on two farms, no evidence of contamination of water was found. Similarly concentrates and feed mixes were found to be uncontaminated and to comply with the manufacturers specification.

## **6.5 FODDER**

### **6.5.1 Sampling**

Fodder (silage and hay) samples were taken for analysis in March 1995 and additional silage samples were taken in November 1997. Samples were taken from silage pit faces or from freshly open bales using a silage corer. Samples were sent to Johnstown Castle. They were split into two. One sample was used for the measurement of silage quality (at Grange Laboratory) and one for mineral analysis (at Johnstown Castle).

### **6.5.2 Fodder 1995. Presentation And Quality Analysis 1995**

Two samples of first cut silage were taken at the Somers farm, one baled and one from the pit face. One sample of second cut was taken from a pit. Two samples of first cut were taken at Ryan's - both baled. Two samples of first cut were taken at the Control farm - both from the pit face. This silage may have been imported from an area outside the control farm itself. A sample of hay was taken from both the Somers and Ryan farms. The hay at the latter farm was bought in and was fed only to a horse.

The results of the Teagasc Feed Quality Analysis on the silage samples have been summarised in Chapter 3 to facilitate assessment of pastures on different farms. The complete data set for all forage samples analysed are presented in Appendix 17.1 - 17.7. Recommended Feed Quality Analysis standards for silage are given in Appendix 17.8. All results are expressed on a dry matter basis. In general the nutritive value of silage from the two Index Farms with one DMD (dry matter digestibility) below 600 g kg<sup>-1</sup> and an additional one below 650 from each of the two farms must be regarded as low. A published survey of silage quality for samples received at Grange had shown that mean DMD for first cut silage for the years 1993-1996 was successively 637, 692, 678 and 695 g kg<sup>-1</sup> (Keating and O'Kiely, 1997a). Digestibility of second cut silage was essentially similar with that of baled silage being reduced by ca 3% on average

(Keating and O'Kiely, 1996b). Silage from Co. Limerick was the third lowest ranked for DMD by county and averaged 647 for first cut over the period 1993-1996.

### 6.5.3 Silage 1995 - Mineral Analysis

With the exception of chromium, nickel, aluminium, titanium, iron and vanadium values of the Somers and Ryan silages, the mineral contents of the silage from the three farms (Appendix 18) fall within the typical ranges obtained for Irish silages. The high titanium values in the silage from the Somers and Ryan farms are indicative of a high degree of soil contamination. This is also reflected in elevated aluminium, iron and fluorine levels and to a lesser extent in values of the other elements on the various farms (Table 6.3). The values for the Control farm silages are more typical of values generally obtained for silages, which will always be soil contaminated to some extent.

### 6.5.4 Hay 1995 - Mineral Analysis

The mineral analyses of the hay samples are recorded in Appendix 19. Mineral contents fall within the typical Irish ranges. Aluminium, iron and titanium are elevated indicating a degree of soil contamination.

### 6.5.5 Silage 1997

Analysis of silages on Somers and Ryan Farms, which were sampled in late 1997 are shown in Appendix 20. Silages were, on average, of better quality than in 1995, i.e. mean DMD 670 and 698 compared to 630 and 635 for Somers and Ryan Farms, respectively. As in 1995, preservation quality was occasionally poor.

**Table 6.3:** The titanium (Ti), aluminium (Al), iron (Fe), chromium (Cr), nickel (Ni), vanadium (V) and fluorine (F) levels (mg kg<sup>-1</sup>) in the silage samples from the Somers, Ryan and Control farms

Ident		Ti	Al	Fe	Cr	Ni	V	F
Somers	Baled (1st Cut)	44	596	361	0.85	3.96	2.57	16.6
	Pit (1st Cut)	104	888	643	1.20	2.11	1.50	25.0
	Pit (2nd Cut)	30	449	341	0.69	3.16	1.88	15.9
Ryan	Baled (1st Cut)	24	254	518	3.00	4.92	2.75	12.4
	Baled (1st Cut)	18	112	463	0.62	2.76	1.29	5.8
Control	Pit (1st Cut)	16	91	106	0.04	1.81	0.31	6.3
	Pit (1st Cut)	17	191	158	0.14	1.94	0.65	6.7

In summary the nutritive value of silages from both Index Farms was normal for the county but low nationally. Silage had a higher nutrition value in 1997 than in 1995 – with DMD's of approximately 680 compared to 630. As with grazed herbage, herbage from fields closed for silage production gave no indication of having suffered pollution from heavy metals.

## **CHAPTER 7**

### **LONGITUDINAL STUDY**

#### **7.1 SOIL AND HERBAGE**

Four farms designated LS 1, 2, 3 and 5 required analysis as part of the Longitudinal Study. These farms were also included in the Retrospective Study as farms 5, 6, 7 and 9, respectively.

Analyses for soil collected in July 1997 from 3 of these farms LS 2, 3 and 5 are shown in Appendix 21.1 and 21.2. Soils were sampled to a depth of 100 mm on two grass and two silage paddocks on each farm. Some of the paddocks clearly had a requirement for P, K and some paddocks on two farms appeared to be low in available copper. Herbages collected at the same time (Appendix 21.3 - 21.4) were also deficient in copper on some paddocks on the same two farms but relationships between soil and herbage values were not good.

Heavy metal (Zn, Cd, Ni, Pb) values for soils from the three farms tended to be slightly elevated (Appendix 21.2) and this was attributed to slight geochemical pollution.

There was an indication of sulphur deficiency in some of the herbages (high N, low S). Sulphur deficiency in herbage is most common in mid-summer (the time of the second silage cut) especially on free draining soils and is nowadays regarded as quite prevalent (Murphy and Boggan, 1988). Selenium levels were lowish and molybdenum levels were moderately elevated in herbage. Comment on two low herbage Mn values on Farm C is deferred until later (Chapter 8.5), when these farms are considered as part of the Retrospective Survey.

This sampling regime was repeated in November 1997 with Farm LS 1 (two paddocks) being included on this occasion. The incidence of some low soil nutrient values was confirmed (Appendix 22.1). Herbage selenium and copper was higher in November. On that occasion molybdenum was slightly raised in some herbage samples (Appendix 22.3). Since Farm LS 1 was not included in the July sampling, additional soil analyses in were preformed on the November soil samples from this farm (Appendix 23).

In summary, phosphorus levels were low on a number of sites. Mild geochemical pollution by Cd was noted (Appendix 21.2 and 23).

#### **7.2 SILAGE ANALYSIS**

Silages collected in November 1996 were collected and analysed. Results together with those found for silage sampled in July 1997 are reported in Appendix 24.1 and 24.2. Preservation quality was erratic. Nutritive values (DMD was poor on some farms. Low values for Mn on Farm C was again noted.

## CHAPTER 8

### RETROPSECTIVE SURVEY

#### 8.1 INTRODUCTION

This was performed to complement the veterinary Retrospective Study which was initiated in December 1995. It covered a maximum of 25 self designated problem farms whose location is shown in Fig. 18. Samples of soil and herbage were taken in July 1997 and again in November 1997. On the first occasion silage samples were also taken.

#### 8.2 SAMPLING AND ANALYSIS

Soils were sampled to a depth of 100 mm on 2 ha plots in July and again in November-December 1997 from one or two grazing and silage areas on each farm. In July 1997, 47 paddocks on 21 farms were sampled and in November 48 paddocks on 22 farms. On this occasion soil was sampled to a depth of 0-100 mm rather than to 0-50 mm that had been done in 1995. It was believed that no loss of accuracy resulted as 0-50 mm sampling on permanent pasture.

Herbage was taken as described earlier (5.2) from each area sampled for soil. Silages (20) and one hay sample were taken from each farm.

Analyses were conducted for a wide range of relevant parameters and constituents using the methodology, described in Appendix 1 and Appendix 10.

Mean levels for soil, herbage and silage parameters for July samples are shown in Table 8.1-8.3 and individual results are shown in Appendices 25.1-25.6. Individual results for November samples are shown in Appendices 25.7-25.9.

Additional sampling and analyses were subsequently conducted on November samples on one farm that had not provided samples in July 1997 (Appendix 26.1-26.3).

**Table 8.1:** Composition of soils (47) from 21 farms participating in the Retrospective Study, July 1997.

Component	Amount (mg kg <sup>-1</sup> )			
	Mean	SD	Min	Max
Cd	1.06	0.73	0.20	4.04
Co	10.3	2.8	3.4	15.6
Cr	25.1	6.7	10.8	47.4
Cu	21.6	10.6	11.6	58.6
F	674	164	330	1070
Ni	35.9	10.4	10.9	59.1
Pb	73.8	112.5	17.1	789.0
Se	1.06	2.06	0.40	14.50
Zn	117.9	49.1	46.4	376.7



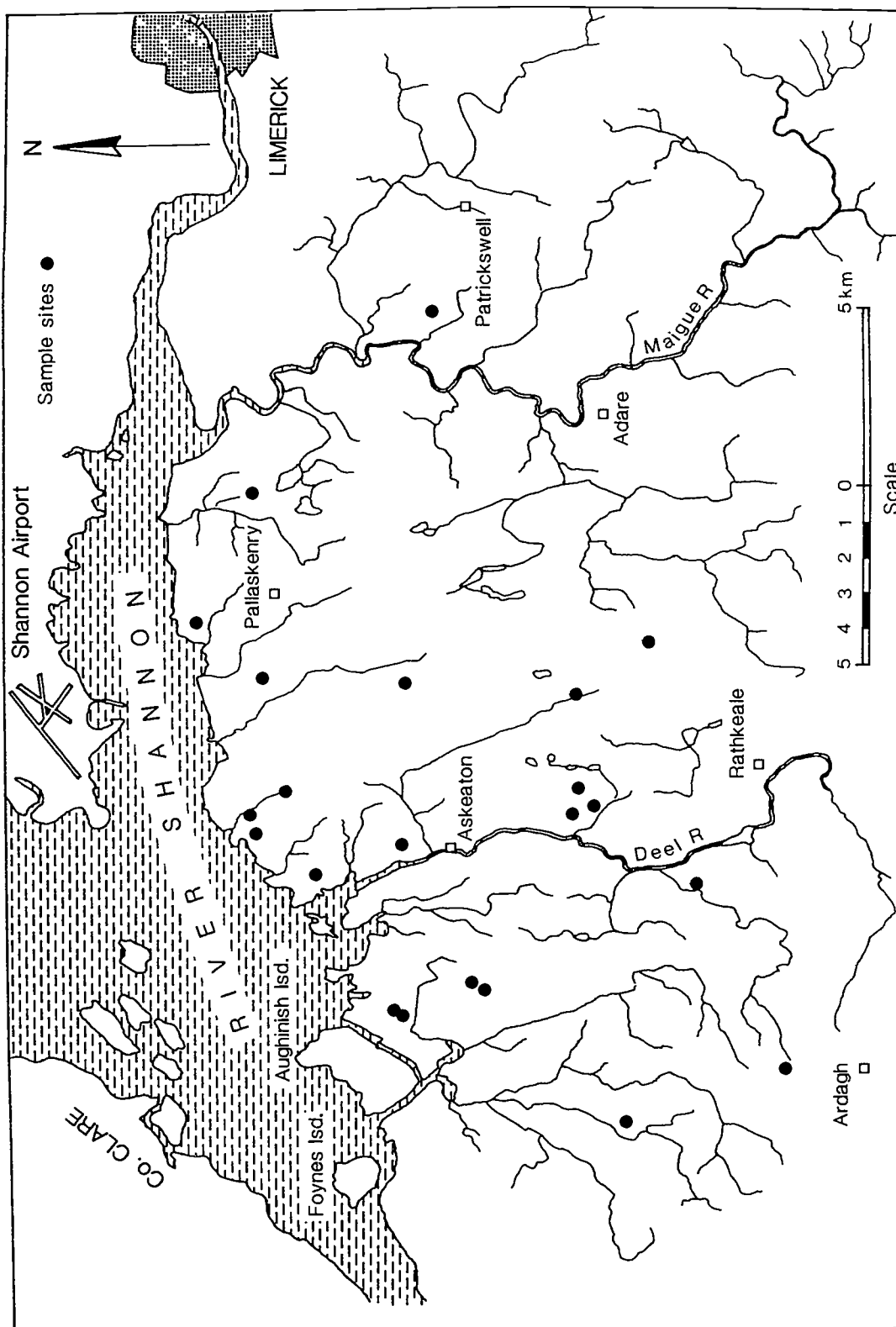


Fig. 18: Location of farms participating in the Retrospective Study.

**Table 8.2:** Composition of herbages (47) from 21 farms participating in the Retrospective Study, July 1997.

Component	Mean	SD	Min	Max
N (g kg <sup>-1</sup> )	32.0	10.1	12.6	48.8
S (g kg <sup>-1</sup> )	3.0	0.6	1.0	4.7
Cd (mg kg <sup>-1</sup> )	0.16	0.25	0.02	1.66
Cr (mg kg <sup>-1</sup> )	0.37	0.26	0.04	1.10
Cu (mg kg <sup>-1</sup> )	10.1	2.3	5.9	15.2
Mo (mg kg <sup>-1</sup> )	2.2	2.7	0.3	17.0
Ni (mg kg <sup>-1</sup> )	2.27	1.19	0.47	5.74
Pb (mg kg <sup>-1</sup> )	0.64	0.75	0.10	4.00
Se (mg kg <sup>-1</sup> )	0.20	0.71	0.03	4.90
Zn (mg kg <sup>-1</sup> )	40.3	30.3	20.0	236.2
Mn (mg kg <sup>-1</sup> )	146	105	8	517

### 8.3 SOIL RESULTS

On all but three farms, departures from normality of soil components were relatively small, reflecting probably geochemical influences, and would have had no toxicological significance for plant or animal. Values for soil pH, and for extractable P, K, Mg, Cu, Zn and Mn were unexceptional, varying from moderately deficient to moderately enriched (Appendix 25.1). Soil pHs in particular were generally on the high side reflecting the limestone parent material. The metals, Cu, Mn and Co were present at normal concentrations. F values were higher than those found in most other parts of Ireland: they were similar to those recorded for the Ryan and Control farms in the 1995 investigation but were lower than those on the Somers farm. Ni values were a little on the high side and Cr (with which Ni is generally positively associated) tended to be low. Se and Pb levels were perhaps slightly elevated on average.

Elevated Cd levels (Appendix 25.2) were attributed to the proximity of the Clare shale out-crop which runs generally in a north-south direction and crosses the Shannon near Foynes. Cd is now viewed as a negative component of soils and levels in excess of 1 mg kg<sup>-1</sup> are generally taken as indicating contamination. The level of contamination, generally 1-2 mg kg<sup>-1</sup> was mild but widespread, extending to more than half of the soils analysed.

Three soils differed considerably from the norm. One soil had a relatively high level of Se which could be considered dangerous to grazing animals: very high levels of this element are associated with the peaty phase of alluvial soils occurring in small pockets in a number of areas including south-west Limerick. A second soil had a particularly high level of Pb, approaching 800 mg kg<sup>-1</sup>. Such a level, although exceeding normal background by a factor of about 30 would not normally have a measurable impact on plant or animal within a small area. Zn in a third soil, in particular, was high, nearly 400 mg kg<sup>-1</sup>. At such a level the possibility of inhibition of plant growth arises. From existing information it seems likely that these three instances of elevated Se, Pb and of Zn had a geochemical origin.

### 8.4 SOIL RESULTS - NOVEMBER 1997

Component values for soils (Appendix 25.7) were very similar to those determined in the July samples. All values were unexceptional. Analysis for heavy metals were not performed on the November samples.

## 8.5 HERBAGE RESULTS - JULY 1997

Analyses for herbage N, P, K, Mg, Na, Ca and S (Appendix 25.3) indicated a fairly normal range with the occasional high value, for instance for S, being balanced by low values (even to the point of being suggestive of S deficiency). With respect to trace components (Appendix 25.4), Se levels, although normal included some very low values, (i.e.  $0.03 \text{ mg kg}^{-1}$ ) - values, which, although low, are not rare. Two of the manganese values at  $8$  and  $20 \text{ mg kg}^{-1}$  were exceptionally low, perhaps the lowest recorded at Johnstown for an Irish herbage: these samples come from soils of exceptionally high pH 7.4, which is a feature in the production of Mn deficient herbage. As noted above soils in the area have generally normal, and arguably even slightly elevated, levels of Mn. Zn and Cu levels were unexceptional. However, a number of samples had elevated Mo. This was not unexpected since the area covered overlaps considerably that delineated in 1966 as having elevated environmental level of this element (Thornton *et al.*, 1966). This suggests the possibility of a more marked elevation of Mo later in the year, since its uptake by plants is strongly influenced by soil moisture.

## 8.6 HERBAGE RESULTS - NOVEMBER 1997

Values for herbage nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), sodium (Na) and sulphur (S) were similar (Appendix 27.8) to those found for the July sampling. Calcium (Ca) was considerably reduced in November samples, a feature that has been encountered previously at this time of year.

Most selenium values were greater in November (Appendix 25.9) than in July, although the high July value for farm 15, silage area at  $4.90 \text{ mg kg}^{-1}$  was reduced to  $0.54 \text{ mg kg}^{-1}$ . Manganese (Mn), zinc (Zn) and copper (Cu) values were similar for both sampling dates. However, molybdenum was on average twice as high in November, averaging  $4.3 \text{ mg kg}^{-1}$ . Three paddocks had molybdenum values exceeding  $10 \text{ mg kg}^{-1}$  whereas an additional 17 herbage had a value of 3.0 or above: this is the level at which interference with copper metabolism in the ruminant may be considered to become significant.

**Table 8.3:** Composition of fodder (21 samples) from farms participating in the Retrospective Study, July 1997.

Component	Mean	SD	Min	Max
N ( $\text{g kg}^{-1}$ )	17.2	3.5	10.6	24.4
S ( $\text{g kg}^{-1}$ )	1.7	0.3	1.2	2.4
Cd ( $\text{mg kg}^{-1}$ )	0.15	0.08	0.04	0.33
Cr ( $\text{mg kg}^{-1}$ )	1.11	0.82	0.28	3.29
Cu ( $\text{mg kg}^{-1}$ )	7.1	2.2	2.9	10.8
Mo ( $\text{mg kg}^{-1}$ )	1.30	0.85	0.50	4.20
Ni ( $\text{mg kg}^{-1}$ )	2.26	1.10	0.47	4.76
Pb ( $\text{mg kg}^{-1}$ )	0.68	0.59	0.13	2.14
Se ( $\text{mg kg}^{-1}$ )	0.08	0.05	0.04	0.23
Zn ( $\text{mg kg}^{-1}$ )	30.4	5.9	19.5	40.5
Mn ( $\text{mg kg}^{-1}$ )	148	97	35.0	313

## **8.7 SILAGE RESULTS**

The 19 silage samples, included in Appendix 25.5 with a sample of hay, were generally adequately preserved except for a sample with a pH of 6.5 and a dry matter content of 629 (a hay!) and these were excluded from statistical evaluation. DMD of many of the samples, however, was clearly less than adequate. Composition of the samples for major elements (Appendix 25.5 and Table 8.3) and trace elements (Appendix 25.6) included values that were less than those found in fresh herbage (Appendices 25.3 and 25.4) for some components, notably N, S and P. Instances, of high Se, Cd, Zn and Pb that were recorded for herbage from silage ground were not corroborated in the silage samples. Three silage samples had Mn values below 40 mg kg<sup>-1</sup>.

## **8.8 ADDITIONAL ANALYSES**

Additional analyses on soil (Appendix 26.1 and 26.2) and on herbage (Appendix 26.3) were performed on samples from farm No. 13 which had not been included in the analytical program for retrospective farms. This brought the total number of farms to 23 in a total of 25 in the survey. The sample was from an area that was neglected and in need of fertilization.

## **8.9 FOLLOW UP INVESTIGATION OF 3 INSTANCES OF SEVERE GEOCHEMICAL POLLUTION**

### **8.9.1 Selenium**

Farm No. 15, silage area was resampled in June of 1998 (Appendix 27.1). The field away from border areas was divided into 8 approximately equal plots of 0.20 ha each. Samples of soils (0-100 mm) and herbage (mature grass for silage) were taken from each plot. The selenium content of soil ranged from 13.5 - 22.5 (mean 17.6: SD 3.8) mg kg<sup>-1</sup> and herbage ranged from 1.20 to 5.40 (mean 2.72: SD 1.4) mg kg<sup>-1</sup> (Appendix 27.1). These values confirmed the belief that selenium toxicity to animals was a possibility when conditions favoured plant uptake of the element. Soil pHs were low 5.3-5.9 (mean 5.5: SD 0.2) which would have militated against the uptake from soil of selenium by herbage.

### **8.9.2 Zinc and Lead**

Soil samples numbering 11 were taken from 0.30 ha areas on Farm No. 24, silage area. Ground had been tilled since the previously sampling. Analysis of samples (Appendix 27.2) confirmed the presence of high soil zinc (221 - 1596; mean 479, SD 405 mg kg<sup>-1</sup>) and lead (93 - 1234; mean 256, SD 329 mg kg<sup>-1</sup>). The area with the highest values was characterised by the presence of darker soil compared to its surrounds. The area most elevated in zinc soil had a higher than normal proportion of the element in plant available form (364 mg l<sup>-1</sup> EDTA extractable) suggesting that it would be phytotoxic especially to newly established plant species.

### **8.9.3 Lead**

Soil was obtained from Farm 31, grazing area, subdivided into 7 sections each of ca 0.15 ha. Soil lead (Appendix 27.3) ranged from 176 - 1653 (mean 613: SD 507 mg kg<sup>-1</sup>). It is now known that the site overlaid a disused lead mine. Whereas grass or other plants would not be expected to suffer growth reduction or to assimilate high quantities of lead, nevertheless the presence of very high amounts in soil could be dangerous to young livestock especially by direct ingestion.

The above investigations confirm earlier elevated measurements on some farms. The conclusion is that there may be a toxicologically (plant or/and animal) significant excess of selenium, zinc and lead on some farms in the Askeaton area with undesirably high molybdenum and cadmium. However, all of these are almost certainly wholly geochemical in origin, with perhaps some input from residues from old mine works.

#### 8.9.4 Metals in Potato Foliage

Foliage with different degrees of chlorosis was taken from potato plants growing in the area of plots 1-6 on Farm 24. Analysis (Table 8.4) showed that zinc content increased in parallel with severity of chlorosis observed in plant. More worrying was elevated cadmium in all three foliage samples. Lead was also elevated in one sample which also exhibited severe growth retardation. Elevated lead level occurred in plants that also appeared desiccated and stunted and could possibly be attributed to soil contamination.

**Table 8.4:** Analyses of potato leaves with various degrees of chlorosis/necrosis sampled on Farm 24, June 1998

Vegetation Colour	N	P (g kg <sup>-1</sup> )	K	Zn	Cu (mg kg <sup>-1</sup> )	Pb	Cd
Green	57.4	3.0	25.7	130	15.0	0.8	3.4
Green/Yellow	28.8	2.0	26.2	249	11.3	1.8	4.2
Yellow	27.8	1.0	26.0	314	8.9	24.9	3.2

#### 8.9.5 Summary

In summary, since the four farms that participated in the longitudinal study also participated in the retrospective study, and differed only in that a large number of analyses that were performed on the former, it is most convenient to consider them all together – a block of nearly 50 soils from 24 farms.

The variation in soil properties displayed by Retrospective Study farms was considerably greater than found for the original three farms, which is not surprising as soil variability is known to increase with area. From a pollution standpoint, three soils had metal (lead, zinc, selenium) at a potentially dangerous level. In addition, many samples had high Mo. However, in spite of the risk, it is clear that these sites do not form part of the animal health problem, as indicated to the investigators. It is possible that serious animal health consequences may arise in unexamined sites in the area as it does immediately to the south, in the Ardagh region, where serious health consequences due to selenium excess are frequently noted. It should be noted in relation to lead and selenium, that an awareness existed at farm level as to the likelihood of their being a problem but in neither instance has a recognisable problem surfaced.

## CHAPTER 9

### ADDITIONAL INVESTIGATIONS

#### 9.1 SOILS

Soils were sampled for three other major purposes.

- (a) Samples of soil were taken from the three farms and analysed for dioxins/furans and PAHs (*c.f.* 4.2) and for polychlorinated biphenyls (PCBs) by Teagasc. The two sampling locations on the Somers, Ryan and Control farms were in each case at a high elevation and open to the north and northwest. The samples were taken to a depth of 50mm using a trowel.

The PCB analysis was conducted using gas-liquid chromatography by the method described by McGrath (1994). Values of 0.79 and 0.71, 0.98 and 0.66, and 1.54 and 1.20  $\mu\text{g kg}^{-1}$  were obtained for the samples from the Somers, Ryan and Control farms, respectively. These values are typical for Irish agricultural soils (McGrath, 1994).

- (b) To assist in the evaluation of the Vole Study. Spot collections of soils were made from the area adjacent to the pier facing Aughinish Island and for the Coole estate, Gort, Co. Galway. These were examined for a range of parameters (Appendix 28.1). Most of these soils were highly alkaline and that probably accounts for their elevated Cd contents. Soil collected near the pier at Askeaton had elevated levels of Ni, Zn and Pb suggestive of human influence. Selenium levels in most of the soils was decidedly low.
- (c) Soil was collected in bulk from a site on the Somers farm and from a Johnstown Castle site with the aid of an implement used to remove shallow sods from golf greens. Soils were dried and sieved to pass a 2 mm mesh. Both soils (Appendix 28.2) appeared to be uncontaminated by heavy metals with the major difference being the high F content of the Askeaton soil.

#### 9.2 INSPECTION OF HEDGEROWS AND GRASSLAND AT ASKEATON

In early June 1999 the Farm RS 05 was visited by experts from Teagasc, Johnstown Castle at the request of the owner to inspect recent damage to hedgerows and pastures. It was claimed that damage had been caused on one or two occasions in the recent past. On arrival at the farm we were informed that the damage was widespread and we would be shown several other locations where damage was claimed to have been done. We were shown the sites as follows:

##### 9.2.1 Farm RS 05

Spotted laurel shrub (*Aucuba japonica*): The shrub was about 2.5 m high and about 1.5m wide and located near the dwelling house and on the south west side of a low stone wall. Most of the leaves on the north western side of the shrub were completely black and dead. The blackness was uniform on one main branch and there was no effect on adjoining branches. There was no gradation of the effect towards the edge of the affected area. The owner said that he noticed the damage about 1<sup>st</sup> April immediately after getting an ammonia-like smell in the atmosphere on the previous night.

Hawthorn (*Crataegous monogyna*) hedge: Some leaf burn and bare twig tips on the north western side of the hawthorn hedge. The effects were greater towards the top of the plants and near gaps in the hedge. Only minor effects were noticed on the sheltered south eastern side of the hedge.

Holly (*Ilex aquifolium*): The shrub showed signs of physical damage and disease. The top leaf canopy of the shrub was thinned out considerably.

#### **9.2.2 Farm RS 28**

Horse chestnut (*Aesculus hippocastanum*) tree: Many leaves with brown margins or large brown areas on the NW side of the tree: There was a distinct gradation from very damaged on the NW facing side to virtually none on the SE side. A nearby macrocarpa (*Cupressus macrocarpa*) tree showed burning effect on the NW side also.

#### **9.2.3 Additional Farm**

Similar damage to horse chestnut to that seen at Farm RS 28 and some damage to hazel (*Corylus avellana*) shrubs on NW side was noted.

#### **9.2.4 Farm RS 17**

Young beech (*Fagus sylvatica*): One tree showed leaves with brown sections on all sides of the plant. In a wooded rockery area hawthorn leaf-burn was present. In a new plantation of Ash (*Fraxinus excelsior*) and oak (*Quercus robur*) there were brown areas on leaves of oak on the western side of the plantation. There was also a large number of oak galls on the young oak trees. Some young ash leaves were withered and black while others were blackened along the leaf edges.

#### **9.2.5 Farm of Liam Somers, Askeaton**

Similar effects were seen on ornamental shrubs and hawthorns as noted for the previous farms. Mr. Somers had complained about the presence of a purple colour on the leaves of grasses during April and in his silage crops. The silage had been harvested and examples of the purple colour were therefore less plentiful. The presence of a pink or purple pigment in ryegrass is very common. It is associated with low supplies of nutrients, especially nitrogen, that are essential for chlorophyll development. The samples found on the farm were typical of the condition. The occurrence of the purple colour in the leaves of grasses was more noticeable than usual this year. A potato crop near the dwelling house sown in mid March was well advanced and in good healthy condition – not showing any damage.

Large parts of the electric fence which was installed 2–3 years ago were badly rusted. Other parts of the fence did not show any signs of rusting.

#### **9.2.6 Farm RS 24 Askeaton**

Similar type damage to hawthorns as seen in the other farms was noted. The affected hawthorns were on the edge of an uncut silage field. The crop in the field was 100% ryegrass and in perfect condition. The leaves were broad and dark green and there was no sign of discolouration in any leaf.

#### **9.2.7 Trees and shrubs at Johnstown, Tipperary and east Co. Limerick**

Samples of similarly damaged hawthorn leaves and shoots were collected at Johnstown Castle and from locations between Limerick City and Tipperary. These locations were: 1) Beside the Limerick - Tipperary road about 12 km east of Limerick. (N 52.37. 208 W 08.28 .992), 2) Two sites on a hillside near Cappamore (N 52.35.816 W 08.27.665). The damage was the same as seen in the Askeaton area. The damage to leaves and shoots in all cases occurred on the side of the hedges exposed to the prevailing winds. About 0.4 km away near a signpost, 'Boher 1km', there was a large horse chestnut tree exhibiting a lot of leaf damage on it's western side. The damage was of a similar nature to that seen at Askeaton but was much more severe.

The only item that was unexplainable in terms of the normal environmental conditions prevailing throughout the country this spring/early summer was the localised damage to the spotted laurel shrub. There was uniform damage on one branch while the adjoining shoots and leaves were completely free from even mild signs of damage. Damage to or disease in the root system of a tree or shrub is often expressed above ground in the death of some branches and leaves. The whole tree or shrub eventually succumbs.

#### **9.2.8 Comment and Conclusion**

We examined hedgerow trees and shrubs in counties Wexford, Tipperary and Limerick. There were mature hawthorn hedges in abundance in the three counties. All hedges showed variability between nearby individual hawthorn bushes as to their seasonal state of development and their foliage colour. For example, one hawthorn bush might be fully finished flowering while the adjoining one might be still in full flower; one might have dark green, tightly clustered leaves on the outer shoots while the next one might have much more widely spaced leaves and of a pale green colour. Ash trees also displayed varying degrees of development of their new-season shoots and leaves. This means that there can be great variability in the degree of damage suffered following exposure to a damaging source.

In all cases damage to trees and shoots in the three counties was of a visually similar nature. Also, damage was worst at the highest parts of the plants. In Tipperary and Limerick damage was worst on the west and north-west facing sides of the trees and hedges. In Wexford damage was most obvious on the southern and south-western sides.

The was most likely caused by the prevailing weather conditions. This may have been frost alone or a more likely combination of frost acting with the prevailing wind to increase the 'chill factor'. The most certain place to find the damage was on the upper slopes of hills in Limerick and Tipperary. Overall conclusions are that there is little damage to the trees and shrubs, except the spotted laurel branch in on Farm RS 06.



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# APPENDIX 1

## ANALYTICAL METHODS

### Appendix 1: Analytical Methods for Soil and Sediments

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pH	Soil-water suspension measured with glass electrode.
Lime Requirement	Soil-buffer (pH 5.0) suspension measured with glass electrode.
Phosphorus Potassium Magnesium	Extracted with Morgan's reagent (acetic acid-sodium acetate buffer pH 4.80). Phosphorous determined colorimetrically, potassium by flamephotometry and magnesium by atomic absorption spectrophotometry.
Sodium	Extraction with ammonium acetate and flamephotometry.
Sulphur	Extraction with Morgan's reagent and nephelometry
Manganese (Easily reducible)	Extracted with calcium nitrate/quinol reagent and determined by atomic absorption spectrophotometry.
Copper Zinc	Extracted with 0.05 M EDTA (ethylenediaminetetracetic acid-disodium salt) buffered to pH 7.0 and contents determined by atomic absorption spectrophotometry.
Arsenic	Extracted by nitric/sulphuric/perchloric acid (triacid) digestion and determined by atomic absorption spectrophotometry using the hydride technique - a modification of the method described by Ihnat and Miller (1977).
Cobalt Manganese	Extracted with hydrochloric acid sp. gr. 1.12 and contents determined by atomic absorption spectrophotometry.
Iodine	Extracted with 2M sodium hydroxide, subjected to digestion with acid and determined by the catalytic reduction of cerium.
Selenium	Tri-acid digestion and Se complex with 2, 3 diammononaphthalene and determined fluorimetrically. Modification of the method described by Analytical Methods Committee (1979).
Mercury	Digestion with nitric/sulphuric acid mixture and oxidation with potassium permanganate. Content determined by cold vapour A.A. (Ure and Shand, 1974).
Molybdenum	Extraction with Tamm's reagent pH 3.3. Content determined colorimetrically with ammonium thiocyanate.
Boron	Extraction with hot water and determined colorimetrically.
Aluminium	Extraction with calcium phosphate and determined by nephelometry.
Fluorine	Fusion with sodium carbonate. Determined by ion electrode
Thallium total lead, cadmium, zinc, copper, nickel, antimony, chromium, iron, vanadium, titanium and aluminium were determined by atomic absorption spectrophotometry following dissolution with hydrofluoric/perchloric acid.	

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The above methods are as described by Byrne (1979) except where indicated.

## APPENDIX 2

### SOIL MOISTURE CONTENT AND LOSS ON IGNITION

**Appendix 2.1:** Soil Moisture Content of Soil Samples From the Somers, Ryan and Control Farms

Ident*	Moisture (g kg <sup>-1</sup> )		
	Somers	Ryan	Control
1	20	37	22
2	21	49	23
3	21	26	25
4	25	31	24
5	24	34	25
6	29	34	23
7	29	34	29
8	25	38	27
9	53	31	29
10	46	29	28
11	19	40	28
12	30	45	22
13	-	29	26
14	22	30	23
15	20	27	23
16	21	31	
17	20	30	
18		28	
19		31	
Mean	27	33	25
SD	10	6	3
Min	19	26	22
Max	53	49	29

\*Sample locations Figs. 8-10.

**Appendix 2.2:** Loss on Ignition of soil from the Somers, Ryan and Control Farms

Indent	Loss on Ignition (g kg <sup>-1</sup> )		
	Somers	Ryan	Control
1	104.7	157.0	115.7
2	98.9	182.1	116.7
3	116.5	96.4	126.1
4	131.6	99.4	123.2
5	124.7	120.9	125.4
6	142.4	124.4	111.1
7	149.4	122.5	121.4
8	134.4	131.7	111.0
9	268.4	114.6	135.5
10	240.4	130.0	136.7
11	234.6	168.0	148.4
12	152.9	173.9	110.6
13		120.6	114.9
14	110.4	138.4	115.1
15	100.7	125.9	120.0
16	120.1	142.1	
17	112.2	136.4	
18		125.4	
19		143.4	
Mean	146.4	134.4	122.1
SD	53.3	23.0	10.9
Min	98.9	96.4	110.6
Max	268.4	182.1	148.4

## APPENDIX 3

**Soil pH, Lime Requirement (LR), Phosphorus (P) , Potassium (K), Magnesium (Mg), Sulphate-Sulphur (S) and Sodium (Na) Values (mg l<sup>-1</sup>) for the Somers, Ryan and Control Farms**

### Appendix 3.1: Somers Farm

Ident*	pH	LR t ha <sup>-1</sup>	P	K	Mg	S	Na
1	6.7	0	10.7	161	145	28.0	23
2	6.6	2.5	8.2	157	158	29.0	14
3	6.8	0	9.6	178	169	23.0	15
4	6.4	4.0	6.5	103	196	20.0	39
5	6.5	3.2	7.0	103	208	18.0	27
6	6.6	2.5	12.5	138	219	18.5	24
7	6.6	2.5	11.5	147	212	21.0	30
8	6.7	0	10.2	170	188	21.5	19
9	7.1	0	2.9	131	260	31.0	N/A
10	7.0	0	7.0	149	262	29.0	N/A
11	6.9	0	8.0	118	196	26.0	N/A
12	6.1	7.2	6.7	143	163	14.0	29
14	6.4	4.0	8.1	80	177	13.0	24
15	6.7	0	11.0	124	156	15.0	25
16	6.5	3.0	6.2	104	150	18.5	22
17	6.3	4.9	4.9	127	167	18.0	24
Mean	6.6	2.1	8.2	133	189	21.5	24
SD	0.3	2.2	2.6	27	36	5.7	6
Min	6.1	0	2.9	80	145	13	14
Max	7.1	7.2	12.5	178	262	31	39

N/A - Not Available

\*Sample locations Fig. 8.

### Appendix 3.2: Ryan Farm

Ident*	pH	LR t ha <sup>-1</sup>	P	K	Mg	S	Na
1	6.0	8.1	7.7	198	240	21.5	N/A
2	6.1	7.2	8.2	300	335	24.0	44
3	6.0	8.4	4.8	65	154	12.0	25
4	6.1	7.2	4.0	94	161	17.0	24
5	5.8	10.6	5.5	97	143	17.0	N/A
6	5.7	11.6	5.3	104	163	16.5	35
7	5.7	11.1	4.4	105	170	16.0	N/A
8	5.8	10.1	4.4	104	167	17.5	37
9	5.9	9.4	3.6	155	162	16.0	34
10	5.8	9.9	5.1	177	198	15.0	23
11	5.9	9.6	5.3	205	234	18.5	28
12	6.0	7.9	5.4	183	227	18.0	N/A
13	6.5	3.0	10.6	92	288	17.0	14
14	6.2	5.9	12.9	140	249	19.5	33
15	6.1	7.7	13.0	131	215	19.5	27
16	6.0	8.4	14.0	99	221	15.0	30
17	6.3	5.4	11.9	164	242	17.0	20
18	6.1	7.4	12.4	111	214	15.0	24
19	6.1	7.7	9.9	109	246	15.0	24
Means	6.0	8.2	7.8	139	212	17.2	28
SD	0.2	2.1	3.6	56	50	2.7	7
Min	5.7	3.0	3.6	65	143	12.0	14
Max	6.5	11.6	14.0	300	335	24.0	44

\*Sample locations Fig. 9.



### Appendix 3.3: Control Farm

Ident*	pH	LR t ha <sup>-1</sup>	P	K	Mg	S	Na
1	5.7	11.6	4.3	69	140	12.0	24
2	5.6	12.1	3.9	68	135	12.0	20
3	5.7	11.3	5.5	144	179	11.5	28
4	5.7	10.9	4.4	126	186	13.0	24
5	5.6	12.4	4.3	146	159	12.0	35
6	5.5	13.1	3.6	128	138	10.0	28
7	5.9	8.8	5.0	140	201	14.0	25
8	5.8	10.4	3.0	107	174	13.0	36
9	5.8	10.6	7.4	192	172	23.0	18
10	5.9	9.6	4.4	132	193	14.0	29
11	5.9	9.1	4.9	230	211	19.0	23
12	5.5	13.3	4.0	89	133	14.0	22
13	5.9	9.4	2.8	148	142	18.5	20
14	5.6	11.9	2.8	102	137	15.0	25
15	5.5	13.1	3.0	125	142	21.5	21
Means	5.7	11.2	4.2	130	163	14.8	25
SD	0.2	1.5	1.2	43	27	3.9	5
Min	5.5	8.8	2.8	68	133	10.0	18
Max	5.9	13.3	7.4	230	211	23.0	36

\*Sample locations Fig. 10.

## APPENDIX 4

### Extractable Soil Micronutrients (mg l<sup>-1</sup>) Boron (B), Manganese (Mn), Copper (Cu), Zinc (Zn) and Molybdenum (Mo) Values\* for the Somers, Ryan and Control Farms

#### Appendix 4.1: Somers Farm

Ident*	B	Mn	Cu	Zn	Mo
1	1.0	280	8.6	5.7	0.24
2	0.6	267	5.5	5.0	0.24
3	1.6	278	4.9	4.2	0.10
4	1.0	222	7.4	7.4	0.23
5	0.7	240	7.1	4.8	0.31
6	1.0	231	6.9	5.7	0.25
7	1.2	171	7.5	4.9	0.23
8	1.0	230	7.6	5.7	0.22
9	1.6	112	3.1	4.2	0.61
10	1.0	171	4.3	3.1	N/A
11	1.0	45	7.2	3.2	0.44
12	1.2	94	4.1	3.5	0.49
14	1.1	178	5.1	3.3	0.16
15	0.8	205	4.2	3.6	0.17
16	1.1	306	4.7	3.7	0.54
17	1.2	200	5.5	3.7	0.67
Mean	1.1	202	5.9	4.5	0.33
SD	0.3	72	1.6	1.2	0.18
Min	0.6	45	3.1	3.1	0.10
Max	1.6	306	8.6	7.4	0.67

\*Sample locations Fig. 8.

## Appendix 4.2: Ryan Farm

Ident*	B	Mn	Cu	Zn	Mo
1	0.7	309	3.1	6.0	0.15
2	2.0	335	3.8	6.8	0.47
3	0.9	600	5.0	5.9	0.25
4	0.7	600	4.0	5.7	0.22
5	0.7	483	3.2	5.5	0.28
6	1.1	535	3.9	6.7	0.36
7	1.1	451	4.2	6.4	0.24
8	0.9	500	4.0	6.8	0.21
9	1.5	363	2.7	4.7	0.42
10	0.7	385	2.7	5.2	0.21
11	1.2	531	3.8	5.8	0.39
12	0.9	507	3.5	6.5	0.25
13	1.6	340	3.7	5.9	0.14
14	1.3	310	3.2	5.6	0.24
15	1.2	338	4.0	6.9	0.24
16	1.2	319	3.7	6.8	0.27
17	1.3	403	7.6	8.2	0.25
18	1.3	353	5.1	7.5	0.23
19	1.5	358	3.9	6.3	0.16
Mean	1.1	422	3.9	6.3	0.27
SD	0.4	99	1.1	0.8	0.09
Min	0.7	309	2.7	4.7	0.14
Max	2.0	600	7.6	8.2	0.47

\*Sample locations Fig. 9

**Appendix 4.3: Control Farm**

<b>Ident*</b>	<b>B</b>	<b>Mn</b>	<b>Cu</b>	<b>Zn</b>	<b>Mo</b>
1	0.7	228	4.2	5.7	0.27
2	1.1	233	4.3	5.4	0.21
3	0.8	242	5.4	5.8	0.19
4	1.2	251	4.7	5.1	0.24
5	0.7	248	3.9	3.6	0.22
6	0.7	188	3.2	3.8	0.36
7	0.7	315	7.8	8.0	0.22
8	1.0	312	6.5	6.5	0.18
9	0.8	299	3.7	5.9	0.28
10	1.0	328	4.8	6.5	0.31
11	0.9	334	5.2	7.5	0.21
12	0.9	248	3.7	5.5	0.27
13	0.5	310	4.0	4.8	0.32
14	1.0	336	3.9	5.0	0.33
15	0.7	304	3.3	5.5	0.27
Mean	0.8	278	4.6	5.6	0.26
SD	0.2	46	1.2	1.2	0.05
Min	0.5	188	3.2	3.6	0.18
Max	1.2	336	7.8	8.0	0.36

\*Sample locations Fig. 10.

## APPENDIX 5

**Total Soil Micronutrients (mg kg<sup>-1</sup>) Iodine (I), Selenium (Se), Cobalt (Co), Manganese (Mn)<sup>1</sup>  
and Fluorine (F) values for the Somers, Ryan and Control Farms**

### Appendix 5.1: Somers Farm

Ident*	I	Se	Co	Mn	F
1	8.5	0.60	7.6	452	800
2	5.9	0.50	7.3	469	800
3	5.4	0.60	7.9	512	700
4	6.1	0.80	6.9	458	930
5	6.2	0.90	7.4	428	900
6	5.5	0.95	6.3	387	1100
7	6.6	0.85	6.0	341	1300
8	6.3	0.95	8.7	459	940
9	6.6	2.45	8.8	332	940
10	5.1	2.75	7.9	171	900
11	6.0	3.90	7.3	181	940
12	4.4	1.10	6.2	205	1000
14	6.2	0.75	6.1	316	1200
15	7.8	0.70	6.3	364	1100
16	5.2	0.65	7.1	306	1100
17	4.7	0.70	6.5	355	1100
Mean	6.0	1.20	7.1	359	984
SD	1.1	0.97	0.9	105	157
Min	4.4	0.50	6.0	171	700
Max	8.5	3.90	8.8	512	1300

\*Sample locations Fig. 8.

## Appendix 5.2: Ryan Farm

Ident*	I	Se	Co	Mn	F
1	5.6	0.55	6.3	573	620
2	7.5	0.60	8.2	1195	720
3	11.3	0.50	9.9	905	800
4	9.0	0.60	9.7	1046	780
5	8.5	0.60	10.5	809	720
6	8.3	0.55	8.8	883	680
7	6.6	0.60	9.1	739	780
8	8.0	0.55	8.8	909	780
9	4.9	0.50	7.7	633	620
10	6.6	0.50	7.5	638	600
11	8.4	0.55	10.8	890	660
12	8.4	0.55	10.1	881	760
13	10.0	0.40	7.1	586	480
14	4.4	0.50	7.8	558	540
15	8.8	0.50	9.3	570	600
16	6.8	0.40	8.6	577	700
17	8.4	0.55	11.0	666	660
18	8.5	0.60	9.6	665	700
19	6.6	0.60	8.9	638	620
Mean	7.7	0.54	8.9	756	675
SD	1.7	0.06	1.3	183	88
Min	4.4	0.40	6.3	558	480
Max	11.3	0.60	11.0	1195	800

\*Sample locations Fig. 9.

### Appendix 5.3: Control Farm

Ident*	I	Se	Co	Mn	F
1	6.6	0.50	8.2	410	700
2	6.7	0.45	8.3	405	740
3	6.8	0.50	9.3	446	750
4	7.0	0.55	8.8	459	820
5	8.2	0.55	9.8	445	950
6	7.2	0.50	9.2	364	840
7	9.6	0.60	8.7	553	580
8	8.2	0.55	8.7	496	580
9	7.8	0.50	8.9	535	620
10	8.4	0.50	9.3	582	660
11	10.9	0.50	9.0	546	640
12	7.5	0.35	7.1	392	700
13	10.2	0.50	8.1	520	600
14	11.0	0.45	8.7	558	620
15	11.6	0.45	8.1	475	660
Mean	8.5	0.50	8.7	479	697
SD	1.7	0.06	0.7	68	107
Min	6.6	0.35	7.1	364	580
Max	11.6	0.60	9.8	582	950

\*Sample locations Fig. 10

## APPENDIX 6

### Soil Iron (Fe), Aluminium (Al) and Titanium (Ti) Values (mg kg<sup>-1</sup>) for the Somers, Ryan and Control Farms

#### Appendix 6.1: Somers Farm

Ident*	Fe	Al	Ti
1	26540	32840	6900
2	24860	35020	5700
3	26680	43460	6800
4	23780	46320	9200
5	25160	43600	8400
6	21720	40480	8500
7	24200	43840	3100
8	27900	49600	4500
9	25000	33300	4100
10	22060	39680	5540
11	25840	40000	5500
12	21540	41520	4300
14	21680	40720	8300
15	22640	39280	7200
16	22400	38960	6500
17	23920	43280	6500
Mean	24120	40744	6315
SD	2000	4468	1771
Min	21540	32840	3100
Max	27900	49600	9200

\*Sample locations Fig. 8.



**Appendix 6.2: Ryan Farm**

Ident*	Fe	Al	Ti
1	16000	33480	5000
2	19780	38640	5600
3	20460	39320	5600
4	20960	39520	5800
5	22800	42300	6600
6	20440	40120	5300
7	24740	41920	7500
8	24820	41140	6400
9	18740	38760	5100
10	20660	39500	4900
11	23440	40440	5500
12	22220	39320	5200
13	18940	36000	4800
14	17620	32800	4500
15	18540	36440	6200
16	16880	29020	3400
17	21480	36220	6500
18	18880	39940	5200
19	20980	37820	6300
Mean	20441	38037	5547
SD	2462	3372	916
Min	16000	29020	3400
Max	24820	42300	7500

\*Sample locations Fig. 9.

### Appendix 6.3: Control Farm

Ident*	Fe	Al	Ti
1	18620	41280	5400
2	19500	40960	6000
3	21500	41640	6200
4	22020	39520	6300
5	25560	43280	6900
6	23680	43840	6700
7	20200	36360	6500
8	18400	33420	3400
9	22120	41140	6300
10	22420	40360	5900
11	24640	38020	5400
12	22940	43020	5600
13	21000	37140	4200
14	22460	36460	5300
15	22120	37460	6100
Mean	21812	39593	5747
SD	2042	3008	933
Min	18400	33420	3400
Max	25560	43840	6900

\*Sample locations Fig. 10.

## APPENDIX 7

**Soil Heavy Metal, Copper (Cu), Zinc (Zn), Chromium (Cr), Nickel (Ni), Vanadium (V),  
Cadmium (Cd), Lead (Pb), Mercury (Hg) and Arsenic (As) total values (mg kg<sup>-1</sup>)  
for the Somers, Ryan and Control Farms**

### Appendix 7.1: Somers Farm

Ident*	Cu	Zn	Cr	Ni	V	Cd	Pb	Hg	As
1	22.9	81	56	46	58	0.48	29	0.14	6.8
2	18.5	85	46	43	48	0.53	31	0.16	15.0
3	19.1	80	48	43	52	0.36	28	0.13	13.6
4	24.6	93	71	55	78	0.61	20	0.10	14.0
5	26.5	95	72	59	81	0.45	20	0.11	13.2
6	21.7	85	63	53	77	0.38	20	0.11	12.6
7	24.8	88	54	53	93	0.43	21	0.11	13.2
8	22.1	80	68	62	80	0.26	22	0.11	15.0
9	18.5	55	52	47	64	0.45	18	0.13	16.0
10	25.3	57	55	49	59	0.66	17	0.18	15.2
11	39.1	79	72	63	71	1.02	22	0.16	14.2
12	18.5	73	51	42	73	0.39	17	0.10	10.0
14	19.6	73	67	49	65	0.37	16	0.08	12.0
15	18.2	74	61	45	73	0.29	15	0.08	11.0
16	19.1	73	53	43	67	0.20	13	0.08	10.0
17	22.2	83	66	53	63	0.24	15	0.08	12.0
Mean	22.5	78	60	50	69	0.45	20	0.12	12.7
SD	5.2	11	9	7	12	0.20	5	0.03	2.4
Min	18.2	55	46	42	48	0.20	13	0.08	6.8
Max	39.1	95	72	63	93	1.02	31	0.18	16.0

\*Sample locations Fig. 8.

## Appendix 7.2: Ryan Farm

Ident*	Cu	Zn	Cr	Ni	V	Cd	Pb	Hg	As
1	13.7	87	41	36	50	0.48	22	0.10	9.3
2	14.2	116	39	37	57	0.75	33	0.12	14.6
3	18.9	135	44	43	60	0.65	54	0.09	20.0
4	16.4	137	43	45	56	0.82	62	0.10	20.0
5	16.6	136	47	47	64	0.77	68	0.14	20.0
6	17.1	132	42	42	56	0.72	57	0.10	18.6
7	24.6	146	51	51	72	0.81	53	0.13	18.4
8	18.6	141	49	48	63	0.90	53	0.09	17.0
9	11.8	98	42	38	55	0.34	28	0.08	13.6
10	13.0	92	41	41	47	0.43	25	0.08	12.0
11	15.8	109	41	46	54	0.88	37	0.12	14.5
12	20.0	108	45	42	52	0.62	30	0.09	15.0
13	24.1	77	40	37	43	0.59	26	0.08	15.0
14	12.7	75	41	51	42	0.40	22	0.08	12.0
15	13.1	80	42	39	53	0.43	28	0.08	14.0
16	13.7	79	35	32	72	0.63	28	0.10	15.5
17	20.3	91	40	44	51	0.57	28	0.12	15.0
18	16.9	89	44	45	53	0.54	31	0.10	14.5
19	14.1	87	43	44	59	0.46	29	0.10	13.0
Mean	16.6	106	43	43	56	0.62	38	0.10	15.4
SD	3.7	25	4	5	8	0.17	15	0.02	3.0
Min	11.8	75	35	32	42	0.34	22	0.08	9.3
Max	24.6	146	51	51	72	0.90	68	0.14	20.0

\*Sample locations Fig. 9.

### Appendix 7.3: Control Farm

Ident*	Cu	Zn	Cr	Ni	V	Cd	Pb	Hg	As
1	15.6	77	41	43	47	0.35	27	0.08	12.0
2	15.1	79	45	43	44	0.32	23	0.10	13.0
3	18.2	81	50	44	44	0.35	25	0.08	11.4
4	18.5	86	52	46	56	0.39	25	0.08	12.5
5	16.9	89	56	51	51	0.43	23	0.08	14.2
6	16.8	86	54	49	49	0.39	20	0.08	14.8
7	22.8	102	42	40	40	0.54	32	0.09	14.5
8	22.0	97	29	33	40	0.36	31	0.11	14.8
9	15.5	106	44	45	50	0.35	27	0.08	13.0
10	18.9	104	45	46	49	0.46	23	0.06	13.0
11	16.9	101	42	45	47	0.46	26	0.08	13.2
12	14.2	91	47	42	49	0.28	18	0.08	13.2
13	14.6	101	50	43	40	0.45	25	0.08	14.8
14	16.6	105	51	45	47	0.28	24	0.08	16.0
15	16.0	101	50	43	43	0.30	22	0.08	12.5
Mean	17.2	94	47	45	46	0.38	25	0.08	13.5
SD	2.5	10	7	8	5	0.08	4	0.01	1.3
Min	14.2	77	29	33	40	0.28	18	0.06	11.4
Max	22.8	106	56	51	56	0.54	32	0.11	16.0

\*Sample locations Fig. 10.

## APPENDIX 8

**Appendix 8:** Re-analysis of soils (0-100 mm) for LR (t ha<sup>-1</sup>), P, K, Mg, Cu and Zn (mg l<sup>-1</sup>), Co and Mn (g kg<sup>-1</sup>) on Somers Farm, November, 1997

<b>Ident</b>	<b>LR t/ha</b>	<b>P</b>	<b>K</b>	<b>Mg</b>	<b>Cu</b>	<b>Zn</b>	<b>Co</b>	<b>Mn</b>
1	2.5	6.5	78	155	8.1	4.9	8.1	665
2	3.7	6.1	126	168	5.4	5.2	8.3	696
3	1.7	8.1	109	189	4.7	4.8	7.8	698
4	0.0	2.3	21	139	6.6	3.3	9.3	740
5	0.0	3.7	38	159	7.5	3.8	9.3	655
6	1.2	5.7	98	236	6.4	5.6	7.9	583
7	0.2	6.9	35	185	8.1	6.9	7.0	471
8	0.0	6.5	121	180	6.5	6.6	9.3	641
9	0.2	3.9	54	141	5.3	5.2	8.3	633
10	0.0	4.0	88	223	3.8	4.7	6.6	270
11	3.2	3.5	151	196	6.1	5.5	8.0	217
12	8.4	3.2	69	90	4.3	3.2	7.0	257
14	4.0	5.2	45	173	3.9	3.2	8.4	413
15	3.7	5.5	48	157	3.8	3.7	7.2	519
16	6.4	2.2	32	138	4.7	3.3	7.9	435
17	6.2	2.2	47	141	8.0	3.9	9.1	576
<hr/>								
Mean	2.6	4.7	73	167	5.9	4.6	8.1	529
SD	2.7	1.8	39	36	1.5	1.2	0.9	169
Min	0.0	2.2	21	90	3.8	3.2	6.6	217
Max	8.4	8.1	151	236	8.1	6.9	9.3	740

## APPENDIX 9

**Appendix 9:** The Mercury (Hg), Selenium (Se), Arsenic (As), Chromium (Cr), Lead (Pb), Iron (Fe), Nickel (Ni), Cadmium (Cd), Cobalt (Co), Vanadium (V), Titanium (Ti) and Thallium (Tl) Levels ( $\text{mg kg}^{-1}$ ) in the sediments from the Somers, Ryan and Control Farms

	Source	Hg	Se	As	Cr	Pb	Fe	Ni	Cd	Co	V	Ti	Tl	
Somers	LS 2	Stream	0.16	1.00	7.8	15.6	8.3	14700	22.0	0.6	8.4	6.3	28	<0.1
	LS 4	Drain	0.16	0.90	8.2	43.7	17.9	24700	41.0	0.6	11.0	20.7	64	<0.1
Ryan	JR 1	Stream	0.21	2.65	12.2	27.2	35.0	20300	32.0	1.8	11.5	15.6	47	<0.1
	JR 3	Trough	0.05	0.95	0.6	11.0	6.9	1030	17.1	1.9	13.4	4.4	14	<0.1
	JR 4	Trough	0.04	0.65	0.2	6.7	2.4	290	15.1	0.3	12.6	2.0	10	<0.1
Control	JOB 1	Trough	0.06	4.65	1.0	12.0	10.5	2180	19.1	0.9	11.8	5.4	25	<0.1

\*Sample locations Figs 15-17.

## APPENDIX 10

### Appendix 10: Analytical Methods for Plant Material

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Calcium Magnesium Copper Zinc Manganese Zinc	Acid digestion and flame atomic absorption spectrophotometry
Phosphorus Nitrogen	Acid digestion and Auto-analyser
Potassium Sodium	Acid digestion and flamephotometry
Sulphur	Nephelometry
Molybdenum	Acid digestion and colorimetry using dithiol : subsequently electrothermal atomic absorption spectrophotometry
Cadmium Lead Nickel Tin Thallium Antimony Vanadium	Acid digestion and electrothermal atomic absorption spectrophotometry
Iron Titanium Aluminum	Dissolution with hydrofluoric acid and flame atomic absorption
Fluorine	Fusion and ion selective electrode.
Boron	Acid digestion and colorimetry using azomethine-H.
Selenium	Tri-acid digestion and Se complexed with 2, 3 diammonaphthene and measured fluorometrically. Modification of method described by Analytical Methods Committee (1979).
Arsenic	Triacid digestion and determined by atomic absorption spectrophotometry using the hydride technique - a modification of the method described by Ihnat and Miller (1977).
Mercury	Digestion with nitric/sulphuric acid mixture and oxidation with potassium permanganate. Content determined by cold vapour atomic absorption spectrophotometry (Ure and Shand, 1974).

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## APPENDIX 11

### Nitrogen (N), Phosphorus (P), Potassium (K), Magnesium (Mg), Sodium (Na), Calcium (Ca) and Sulphur (S) Content (g kg<sup>-1</sup>) of the Herbage on the Somers, Ryan and Control Farms

#### Appendix 11.1: Somers Farm

Ident*	N	P	K	Mg	Na	Ca	S
1	41	4.2	30	2	2.9	7	2.4
2	39	4.2	30	2	3.6	5.9	3.9
3	43	4.5	33	2.1	2.9	6	4.1
4	21	3	29	1.4	2.2	6	1
5	19	3.3	30	1.4	2.8	6	2
6	39	4.1	30	2.1	3.6	7.5	3
7	43	4.5	31	2.3	3.4	7.2	2.9
8	22	2.9	28	1.4	1.4	7.7	2.6
9	29	3.2	27	1.5	1.7	8.1	3.5
10	36	4.5	33	1.7	1.7	7.2	3.5
11	39	4.8	32	2	2.7	8.5	3.1
12	39	4.6	32	1.8	2.2	5.9	3.8
14	24	3.4	32	1.4	1	5.6	2.3
15	20	3.2	33	1.4	1.1	5.5	1.6
16	26	3.3	35	1.4	1.9	5.5	2.3
17	23	3.1	32	1.6	2.6	5.6	2
Mean	31	3.8	31	1.7	2.4	6.6	2.8
SD	9	0.7	2	0.3	0.8	1.0	0.9
Min	19	2.9	27	1.4	1	5.5	1.0
Max	43	4.8	35	2.3	3.6	8.5	4.1

\*Sample locations Fig. 8.

## Appendix 11.2: Ryan Farm

Ident*	N	P	K	Mg	Na	Ca	S
1	27	3.5	26	1.6	2	5.1	3.3
2	26	3.4	28	1.5	1.2	5.6	3.6
3	21	3.3	20	1.8	4.8	6	3.2
4	18	3.2	22	1.7	3.6	6.1	2.7
5	27	3.8	19	1.8	4	5.7	3.2
6	24	3.8	19	1.7	3.3	5.7	3.6
7	25	3.8	20	1.8	3.8	5.5	3.9
8	24	3.9	19	1.8	4	5.6	2.9
9	36	3.7	22	2.1	3.6	5.4	3.9
10	38	4.4	27	2.3	3.1	5.5	3.6
11	29	3.8	25	1.8	3.3	6.5	3.4
12	30	3.6	24	1.8	3.4	5.8	4.1
13	41	4.9	31	2.5	1.5	6.6	4.9
14	39	5.5	30	2.3	2.8	5.8	4.9
15	37	5	27	2.3	2.1	5.9	4
16	37	5.1	27	2.2	2.6	5.8	4.4
17	40	5	32	2.1	1.9	6	4.4
18	39	4.5	29	2.2	2	5.8	3.4
19	43	4.5	22	2.2	4.6	6	4.5
Mean	32	4.1	25	2.0	3.0	5.8	3.8
SD	8	0.7	4	0.3	1.0	0.4	0.6
Min	18	3.2	19	1.5	1.2	5.1	2.7
Max	43	5.5	32	2.5	4.8	6.6	4.9

\*Sample locations Fig. 9.

### Appendix 11.3: Control Farm

Ident*	N	P	K	Mg	Na	Ca	S
1	25	3.1	29	1.6	4.2	4.7	2.3
2	25	2.9	31	1.6	4	4.5	2.5
3	33	2.6	24	1.5	5.3	4.1	3.2
4	34	2.6	30	1.6	5	4.5	3.5
5	28	3	28	1.7	6	3.9	2.5
6	28	2.8	24	1.8	5.8	4	3.2
7	35	3.8	24	1.9	4.4	4.2	3.6
8	38	3.3	22	2.0	6.2	4.5	3
9	37	2.5	26	1.4	2.6	4.7	3.8
10	34	2.9	24	1.7	4	4.8	2.8
11	28	3.3	27	1.7	3	5	3.5
12	31	2.8	16	1.7	7.6	3.8	3.7
13	26	2.2	22	1.5	3.5	4	1.8
14	18	2	19	1.3	4.2	3.1	2.4
15	23	2.1	18	1.5	5.8	4.6	2.5
Mean	30	2.8	24	1.6	4.8	4.3	3.0
SD	6	0.5	4	0.2	1.3	0.5	0.6
Min	18	2	16	1.3	2.6	3.1	1.8
Max	38	3.8	31	2.0	7.6	5.0	3.8

\*Sample locations Fig. 10.

## APPENDIX 12

### Manganese (Mn), Copper (Cu), Molybdenum (Mo), Zinc (Zn), Iron (Fe), Iodine (I), Selenium (Se), Boron (B) and Fluorine (F) content (mg kg<sup>-1</sup>) of the Herbage on the Somer, Ryan and Control Farms

#### Appendix 12.1: Somers Farm

Ident*	Mn	Cu	Mo	Zn	Fe	I	Se	B	F
1	59	12.7	2.1	26	389	0.16	0.05	9.4	10.0
2	61	11.8	2.0	27	418	0.24	0.03	8.8	14.0
3	81	9.6	2.3	28	150	0.16	0.03	9.4	4.6
4	62	7.3	1.4	16	72	0.14	0.03	6.8	2.9
5	60	7.0	1.6	17	64	0.11	0.06	6.3	2.7
6	35	10.4	2.8	27	146	0.12	0.14	8.0	4.2
7	61	11.7	2.4	32	283	0.15	0.08	8.4	8.6
8	58	6.1	2.3	19	248	0.15	0.05	8.8	5.2
9	61	7.0	2.6	25	424	0.29	0.26	8.0	12.0
10	76	8.2	1.9	23	322	0.18	0.52	9.0	12.0
11	106	11.5	1.4	33	1240	0.54	0.63	11.2	46.0
12	171	9.6	1.1	31	686	0.32	0.09	9.8	32.0
14	40	8.2	1.6	20	58	0.10	0.04	6.3	4.8
15	45	7.1	1.3	18	52	0.10	0.02	4.7	3.9
16	78	7.2	1.6	21	69	0.14	0.03	5.6	3.9
17	99	7.6	1.6	20	69	0.13	0.02	7.7	3.2
Mean	72	8.9	1.9	24	293	0.19	0.13	8.0	10.6
SD	33	2.1	0.5	5	311	0.11	0.18	1.7	11.9
Min	35	6.1	1.1	16	52	0.1	0.02	4.7	2.7
Max	171	12.7	2.8	33	1240	0.54	0.63	11.2	46.0

\*Sample locations Fig. 8.

## Appendix 12.2: Ryan Farm

Ident*	Mn	Cu	Mo	Zn	Fe	I	Se	B	F
1	170	8.7	2.3	25	373	0.10	0.06	4.8	10.5
2	108	9.1	2.5	21	154	0.12	0.06	8.3	7.2
3	284	8.6	1.2	22	307	0.55	0.10	6.6	7.8
4	214	6.4	1.9	19	93	0.18	0.04	4.5	5.2
5	428	10.0	2.1	34	310	0.24	0.09	6.2	6.8
6	522	8.8	1.8	33	550	0.38	0.10	6.4	14.0
7	376	8.5	2.2	30	288	0.14	0.08	6.8	8.8
8	377	8.5	1.8	29	423	0.20	0.08	6.7	12.0
9	277	10.5	1.8	32	210	0.16	0.05	7.2	9.2
10	213	9.9	1.9	33	216	0.13	0.04	7.7	7.4
11	179	8.7	2.1	27	708	0.20	0.07	7.2	13.5
12	200	8.8	2.4	27	413	0.31	0.07	6.4	11.0
13	104	11.8	2.1	32	399	0.31	0.07	7.6	11.0
14	142	10.6	2.2	34	577	0.24	0.05	5.6	18.0
15	263	12.0	1.9	39	1212	0.83	0.09	7.2	32.0
16	229	10.5	3.3	36	572	0.46	0.07	11.7	10.0
17	130	12.9	2.3	35	749	0.84	0.06	7.5	17.0
18	165	12.8	3.4	38	341	0.18	0.04	6.5	9.0
19	159	11.6	2.2	33	350	0.17	0.07	7.2	7.4
Mean	239	9.9	2.2	30	432	0.30	0.07	7.0	11.5
SD	115	1.7	0.5	6	259	0.22	0.02	1.5	6.0
Min	104	6.4	1.2	19	93	0.10	0.04	4.5	5.2
Max	522	12.9	3.4	39	1212	0.84	0.1	11.7	32.0

\*Sample locations Fig. 9.

### Appendix 12.3: Control Farm

Ident*	Mn	Cu	Mo	Zn	Fe	I	Se	B	F
1	138	7.8	0.5	24	64	0.12	0.02	5.7	3.2
2	180	9.2	0.7	25	73	0.15	0.03	5.6	3.0
3	97	8.3	1.6	23	103	0.14	0.03	8.8	3.5
4	120	9.6	0.9	27	126	0.15	0.03	4.6	4.0
5	132	8.6	0.6	27	125	0.16	0.04	7.1	4.0
6	216	8.6	0.7	27	236	0.17	0.06	5.4	8.4
7	115	10.1	1.2	29	106	0.11	0.04	5.9	4.8
8	159	12.2	2.0	29	118	0.10	0.04	5.8	7.6
9	165	10.0	1.7	26	285	0.16	0.04	6.2	8.4
10	138	8.6	1.2	31	412	0.24	0.06	8.0	13.0
11	136	8.6	1.2	31	413	0.12	0.05	8.7	12.0
12	142	7.5	0.6	29	112	0.13	0.03	7.0	5.0
13	181	9.6	0.7	28	73	0.16	0.04	7.2	2.9
14	131	6.7	0.3	26	59	0.14	0.07	6.5	2.2
15	166	7.8	1.0	25	72	0.10	0.02	6.3	2.0
Mean	148	8.9	1.0	27	158	0.14	0.04	6.5	5.6
SD	30	1.3	0.5	2	121	0.03	0.01	1.3	3.5
Min	97	6.7	0.3	23	59	0.10	0.02	4.6	2.0
Max	216	12.2	2	31	413	0.24	0.07	8.8	13.0

\*Sample locations Fig. 10.

## APPENDIX 13

**Arsenic (As), Mercury (Hg), Lead (Pb), Chromium (Cr), Cadmium (Cd), Nickel (Ni), Titanium (Ti),  
Aluminium (Al) and Vanadium (V) Content (mg kg<sup>-1</sup>) of the Herbage on the  
Somers, Ryan and Control Farms**

### Appendix 13.1: Somers Farm

Ident	As	Hg	Pb	Cr	Cd	Ni	Ti	Al	V
1	0.60	0.024	2.23	1.26	0.13	2.89	57.3	536	2.40
2	0.50	0.028	1.94	0.74	0.08	2.01	63.5	562	3.08
3	0.75	0.024	0.86	0.40	0.07	2.22	16.9	164	2.07
4	0.10	0.016	0.78	0.33	0.09	1.47	3.7	45	0.65
5	0.82	0.020	0.81	0.22	0.08	0.95	1.9	51	0.51
6	0.60	0.024	1.15	0.34	0.08	1.20	13.9	135	1.07
7	0.50	0.024	1.37	0.54	0.06	1.75	29.9	417	2.25
8	0.12	0.024	0.97	0.60	0.01	1.29	31.3	330	2.05
9	0.75	0.016	1.32	0.83	0.06	1.09	46.7	556	2.48
10	0.82	0.016	1.41	0.88	0.11	1.53	35.0	446	1.85
11	1.20	0.020	2.21	2.15	0.19	3.16	109.0	1763	4.90
12	0.50	0.016	1.72	1.10	0.14	1.92	87.9	822	2.81
14	0.50	0.020	0.76	0.29	0.08	0.93	9.6	32	0.23
15	0.37	0.020	0.55	0.34	0.07	0.90	6.0	61	0.04
16	0.10	0.016	0.77	0.29	0.05	1.44	13.2	43	0.41
17	0.37	0.020	0.78	0.35	0.14	2.52	7.2	48	0.41
Mean	0.54	0.021	1.23	0.67	0.09	1.70	33.3	376	1.70
SD	0.30	0.004	0.54	0.50	0.04	0.70	31.9	446	1.32
Min	0.10	0.016	0.55	0.22	0.01	0.90	1.90	32	0.04
Max	1.20	0.028	2.23	2.15	0.19	3.16	109	1763	4.90

\*Sample locations Fig. 8.

## Appendix 13.2: Ryan Farm

Ident*	As	Hg	Pb	Cr	Cd	Ni	Ti	Al	V
1	0.15	0.028	1.79	0.80	0.17	1.74	87.3	371	3.33
2	0.50	0.024	2.41	0.82	0.15	2.01	35.0	161	2.26
3	0.37	0.016	2.38	0.73	0.10	2.57	52.6	340	2.79
4	0.30	0.024	2.04	0.60	0.13	2.30	36.1	180	1.54
5	0.75	0.020	3.27	0.73	0.20	2.00	49.6	381	5.13
6	1.12	0.024	3.48	1.30	0.18	4.43	91.4	702	5.56
7	0.37	0.016	2.59	0.72	0.19	4.31	62.1	319	4.34
8	0.42	0.020	2.43	0.89	0.15	4.46	75.0	492	5.30
9	0.55	0.020	2.83	0.79	0.25	3.10	71.5	351	3.77
10	0.08	0.012	2.27	0.56	0.22	2.55	53.0	235	2.74
11	1.25	0.020	2.46	1.23	0.07	2.21	116.0	704	4.22
12	0.55	0.020	1.68	0.70	0.12	2.17	81.9	446	3.12
13	0.75	0.016	2.77	1.13	0.19	1.53	58.6	557	2.82
14	0.75	0.024	2.50	0.99	0.10	2.38	59.8	748	3.40
15	1.12	0.024	4.49	2.35	0.21	4.75	161.0	2125	6.81
16	0.55	0.016	3.44	1.09	0.22	3.50	76.2	876	4.47
17	0.50	0.024	3.20	1.27	0.13	3.36	102.4	1066	4.42
18	0.42	0.010	2.80	0.78	0.13	2.85	48.9	446	3.59
19	0.55	0.020	2.90	0.69	0.20	3.40	37.5	377	2.07
Mean	0.58	0.020	2.72	0.96	0.16	2.93	71.4	572	3.77
SD	0.32	0.005	0.66	0.41	0.05	0.99	32.1	445	1.33
Min	0.08	0.01	1.68	0.56	0.07	1.53	35.0	161	1.54
Max	1.25	0.028	4.49	2.35	0.25	4.75	161.0	2125	6.81

\*Sample locations Fig. 9.



### Appendix 13.3: Control Farm

Ident*	As	Hg	Pb	Cr	Cd	Ni	Ti	Al	V
1	0.30	0.024	0.71	0.35	0.11	1.97	7.2	50	0.39
2	0.15	0.024	0.90	0.37	0.11	2.71	6.6	72	0.26
3	0.15	0.024	1.28	0.56	0.05	2.13	15.0	158	0.87
4	0.10	0.016	1.47	0.55	0.05	2.12	44.9	140	0.92
5	0.10	0.020	1.49	0.40	0.08	1.92	15.0	151	0.54
6	0.35	0.028	1.11	0.71	0.09	2.64	44.9	383	1.17
7	0.17	0.024	1.14	0.38	0.08	1.84	16.1	155	1.12
8	0.62	0.020	1.82	0.44	0.09	1.89	13.2	151	0.90
9	0.30	0.024	1.77	0.67	0.10	2.52	31.2	381	0.87
10	0.17	0.020	3.35	0.91	0.07	2.71	48.8	603	1.31
11	0.10	0.024	2.65	0.79	0.04	2.33	49.1	571	1.95
12	0.08	0.020	1.86	0.35	0.04	3.77	15.1	147	0.80
13	0.10	0.020	1.53	0.25	0.08	1.75	2.0	43	0.24
14	0.08	0.024	1.38	0.23	0.08	2.17	1.7	52	0.08
15	0.08	0.016	1.17	0.31	0.09	2.43	7.0	78	0.36
Mean	0.19	0.022	1.58	0.48	0.08	2.33	21.2	209	0.79
SD	0.15	0.003	0.68	0.21	0.02	0.51	17.6	185	0.49
Min	0.08	0.016	0.71	0.23	0.04	1.75	1.7	43	0.08
Max	0.62	0.028	3.35	0.91	0.11	3.77	49.1	603	1.95

\*Sample locations Fig.10.

## APPENDIX 14

### Mineral Content of the Two Biological Samples taken from the Ryan Farm

**Appendix 14.1:** The macronutrient concentration ( $\text{g kg}^{-1}$ ) Nitrogen (N), Phosphorus (P), Potassium (K), Magnesium (Mg), Sodium (Na), Calcium (Ca) and Sulphur (S)

	N	P	K	Mg	Na	Ca	S
"Aquatic plant"	36.3	4.3	38.3	2.0	8.5	37.9	7.8
"Algal mat"	18.7	0.3	22.5	2.2	0.6	125.9	8.2

**Appendix 14.2:** The Manganese (Mn), Copper (Cu), Molybdenum (Mo), Zinc (Zn), Iron (Fe), Selenium (Se), Iodine (I), Cadmium (Cd), Chromium (Cr) and Lead (Pb), Nickel (Ni) Concentrations ( $\text{mg kg}^{-1}$ ) in the "Aquatic plant" and the "Algal mat" samples taken from the Ryan Farm

	Mn	Cu	Mo	Zn	Fe	Se	I	Cd	Cr	Pb	Ni
"Aquatic plant"	1643	17.5	1.20	68.1	8510	1.00	N/A	0.63	7.8	13	12.2
"Algal mat"	51	21.9	0.09	59.5	282	0.55	6	0.07	0.27	4.2	1.7

**Appendix 14.3:** The Aluminium (Al), Titanium (Ti), Vanadium (V), Thallium (Tl), Arsenic (As), Mercury (Hg) and Flourine (F) Content ( $\text{mg kg}^{-1}$ ) of the "Aquatic plant" and the "Algal mat" samples taken from the Ryan Farm

	Al	Ti	V	Tl	As	Hg	F
"Aquatic plant"	3550	433	12.5	0.14	4.25	0.032	N/A
"Algal mat"	238	36	11.2	<0.5	0.038	0.016	23

N/A - Not available

## APPENDIX 15

### Summary of Water Analysis on the Somers, Ryan and Control Farms

**Appendix 15.1:** Analysis Results of the Tap Water Samples Taken From the Somers, Ryan and Control Farms and the Corresponding EU MAC Value for Drinking Water

Test		Somers	Ryan	Control	SI No.81 of 1988 EU MAC Value
pH		7.4	7.5	7.4	6-9
TON*	mg l <sup>-1</sup>	7.2	3.2	8.0	11.3
NH <sub>4</sub> -N	mg l <sup>-1</sup>	<0.1	<0.1	<0.1	0.3
P	mg l <sup>-1</sup>	<0.005	<0.005	<0.005	2.182
K	mg l <sup>-1</sup>	8.1	4.7	42.5	12.0
Ca	mg l <sup>-1</sup>	128	110	123	200
Mg	mg l <sup>-1</sup>	8.5	9.6	14.9	50
Na	mg l <sup>-1</sup>	21.3	20.1	23.5	150
Cl	mg l <sup>-1</sup>	37.4	30.7	42.1	250
SO <sub>4</sub>	mg l <sup>-1</sup>	23	21	30	250
Hardness	mg l <sup>-1</sup> CaCO <sub>3</sub>	356	314	370	
Suspended Solids	mg l <sup>-1</sup>	18	1	10	0
COD	mg l <sup>-1</sup>	<5	<5	<5	0
BOD	mg l <sup>-1</sup>	<5	<5	<5	0
Total Coliform	100ml <sup>-1</sup>	95	1	44	0
Faecal Coliform	100 ml <sup>-1</sup>	28	0	3	0
Conductivity	µS cm <sup>-1</sup> at20°C	840	760	945	1500
Cu	µg l <sup>-1</sup>	<10	28	38	500
Fe	µg l <sup>-1</sup>	54	39	58	200
Mn	µg l <sup>-1</sup>	10	<10	<10	50
Zn	µg l <sup>-1</sup>	<10	13	15	1000
F	µg l <sup>-1</sup>	142	84	127	1000
B	µg l <sup>-1</sup>	7	9	13	2000
Pb	µg l <sup>-1</sup>	<10	<10	<10	50
Cd	µg l <sup>-1</sup>	<2	<2	<2	5
Cr	µg l <sup>-1</sup>	<5	<5	<5	50
Al	µg l <sup>-1</sup>	29	<20	43	200
Ni	µg l <sup>-1</sup>	<10	<10	<10	50
Se	µg l <sup>-1</sup>	0.225	0.125	0.325	10
Hg	µg l <sup>-1</sup>	0.16	0.06	0.16	1.0
As	µg l <sup>-1</sup>	1.95	1.65	2.50	50
CN	µg l <sup>-1</sup>	0.006	0.001	0.004	50

\*TON = Total Oxidised Nitrogen

**Appendix 15.2:** Analysis Results of the Stream and Drain Water Samples Taken on the Somers and Ryan Farms and the Corresponding EU Surface Water Standard

Test		Somers - Stream	Ryan - Stream	Somers - Drain	SI No. 294 of 1988 EU Surface Water Regulation
pH		8.0	7.8	8.0	5.5-8.5
TON	mg l <sup>-1</sup>	1.3	1.3	2.2	11.3
NH <sub>4</sub> -N	mg l <sup>-1</sup>	<0.1	<0.1	<0.1	0.2
P	mg l <sup>-1</sup>	0.025	<0.005	<0.005	0.22
K	mg l <sup>-1</sup>	3.8	3.1	2.2	-
Ca	mg l <sup>-1</sup>	126	112	123	-
Mg	mg l <sup>-1</sup>	6.1	8.0	5.8	-
Na	mg l <sup>-1</sup>	20.8	9.3	18.9	-
Cl	mg l <sup>-1</sup>	32.7	26.3	33.5	250
SO <sub>4</sub>	mg l <sup>-1</sup>	19.0	12.0	21.0	200
Hardness	mg l <sup>-1</sup> CaCO <sub>3</sub>	339	317	331	
Suspended Solids	mg l <sup>-1</sup>	20	29	<1	
COD	mg l <sup>-1</sup>	<5	<5	5	
BOD	mg l <sup>-1</sup>	2.1	2.4	6.6	5
Total Coliform	100ml	66	90	15	
Faecal Coliform	100 ml	15	9	1	
Conductivity	µS cmat20°C	765	700	775	1000
Cu	µg l <sup>-1</sup>	<10	16	11	50
Fe	µg l <sup>-1</sup>	101	40	61	200
Mn	µg l <sup>-1</sup>	<10	40	<10	50
Zn	µg l <sup>-1</sup>	<0.01	<0.01	<0.01	3
F	µg l <sup>-1</sup>	138	120	151	1000
B	µg l <sup>-1</sup>	18	11	10	2000
Pb	µg l <sup>-1</sup>	<10	<10	<10	50
Cd	µg l <sup>-1</sup>	<2	<2	<2	5
Cr	µg l <sup>-1</sup>	<5	<5	<5	50
Al	µg l <sup>-1</sup>	36	32	24	-
Ni	µg l <sup>-1</sup>	<10	<10	<10	-
Se	µg l <sup>-1</sup>	0.275	0.188	0.250	10
Hg	µg l <sup>-1</sup>	0.20	0.08	0.16	1
As	µg l <sup>-1</sup>	1.25	0.38	1.95	50
CN	µg l <sup>-1</sup>	<1	1	4	50

\*TON = Total Oxidised Nitrogen

**Appendix 15.3:** Analysis Results of Trough Water Samples Taken From the Somers, Ryan and Control Farms with the Corresponding EU MAC Value for Drinking Water

Test		Somers	Ryan			Control	S1 No. 81 of 1988 EU MAC
		LS 5	JR 3	JR5	JR 7	JOB1	
pH		8.1	8.9	8.0	8.7	8.3	6-9
TON	mg l <sup>-1</sup>	4.6	0.3	1.4	1.0	2.7	11.3
NH <sub>4</sub> -N	mg l <sup>-1</sup>	<0.1	<0.1	<0.1	<0.1	<0.1	0.3
P	mg l <sup>-1</sup>	<0.005	<0.005	<0.005	<0.005	<0.005	2.182
K	mg l <sup>-1</sup>	7.9	6.3	4.8	6.6	15.9	12.0
Ca	mg l <sup>-1</sup>	124	27	93	42	56	200
Mg	mg l <sup>-1</sup>	8.3	8.0	9.9	7.1	12.1	50
Na	mg l <sup>-1</sup>	21.8	23.4	20.3	26.5	20.5	150
Cl	mg l <sup>-1</sup>	36.5	39.6	33.9	45.2	38.2	250
SO <sub>4</sub>	mg l <sup>-1</sup>	23	25	22	4	23	250
Hardness	mg l <sup>-1</sup> CaCO <sub>3</sub>	343	103	373	134	190	
Suspended Solids	mg l <sup>-1</sup>	<1	6	1	5	17	0
COD	mg l <sup>-1</sup>	<5	<5	<5	8	<5	0
BOD	mg l <sup>-1</sup>	2.3	3.2	2.1	2.8	3.6	0
Total Coliform	100ml <sup>-1</sup>	48	0	68	3	0	0
Faecal Coliform	100 ml <sup>-1</sup>	42	0	38	0	0	0
Conductivity	μS cm <sup>-1</sup> at20°C	820	330	625	400	735	1500
Cu	μg l <sup>-1</sup>	13	20	<10	<10	50	500
Fe	μg l <sup>-1</sup>	45	32	40	145	49	200
Mn	μg l <sup>-1</sup>	<10	<10	<10	51	<10	50
Zn	μg l <sup>-1</sup>	46	17	<10	57	12	1000
F	μg l <sup>-1</sup>	133	84	91	87	131	1000
B	μg l <sup>-1</sup>	12	14	10	17	13	2000
Pb	μg l <sup>-1</sup>	<10	<10	<10	<10	<10	50
Cd	μg l <sup>-1</sup>	<2	<2	<2	<2	<2	5
Cr	μg l <sup>-1</sup>	<5	<5	<5	<5	<5	50
Al	μg l <sup>-1</sup>	<20	23	<20	72	62	200
Ni	μg l <sup>-1</sup>	<10	<10	<10	<10	<10	50
Se	μg l <sup>-1</sup>	0.225	0.02	0.10	0.125	0.500	10
Hg	μg l <sup>-1</sup>	0.32	0.20	0.08	0.04	0.04	1.0
As	μg l <sup>-1</sup>	0.88	1.88	0.18	0.33	0.25	50
CN	μg l <sup>-1</sup>	4	1	<1	<1	2	50

\*TON = Total Oxidised Nitrogen

## APPENDIX 16

### The Mineral Composition of the Concentrate Feeds Collected on the Somers and Ryans Farms

**Appendix 16.1:** The Dry Matter (DM), Phosphorus (P), Potassium (K), Magnesium (Mg), Sodium (Na) and Calcium (Ca) Values ( $\text{g kg}^{-1}$ ) for the concentrate feed samples collected on the Somers and Ryan Farms with their certified values where appropriate

Ident		DM	P	K	Mg	Na	Ca
Somers Beef dairy nuts	found	862	5.2	11	8.40	2.0	16
	certified	860			9.45		
Beef nuts	found	842	4.4	14	2.90	5.7	11
	certified	860			2.70		
Calf nuts	found	819	4.8	13	2.80	2.1	12
	certified	860			2.34		
Ryan Beef dairy nuts	found	839	5.5	15	8.50	2.4	14
	certified	861			9.11		

**Appendix 16.2:** The Copper (Cu), Zinc (Zn), Manganese (Mn), Iodine (I), Iron (Fe), Cobalt (Co) and Selenium (Se) content ( $\text{mg kg}^{-1}$ ) of the concentrates from the Somers and Ryan Farms with their certified values where appropriate

		$\text{mg kg}^{-1}$						
		Cu	Zn	Mn	I	Fe	Co	Se
Somers Beef dairy nuts	found	68	128	152	8.2	970	3.0	0.82
	certified	60						0.60
Beef nuts	found	23	72	95	4.0	550	2.1	0.29
	certified	25						0.15
Calf nuts	found	85	118	127	5.6	310	1.9	0.40
	certified	50						0.30
Ryan Beef dairy nuts	found	56	124	118	7.6	890	4.2	0.64
	certified	60						0.60

**Appendix 16.3:** The Chromium (Cr), Lead (Pb), Nickel (Ni), Cadmium (Cd), Mercury (Hg), Tin (Sn), Vanadium (V), Titanium (Ti), Thallium (Tl) and Fluorine (F) content (mg kg<sup>-1</sup>) of the concentrate from the Somers and Ryans Farms

	Cr	Pb	Ni	Cd	Hg	Sn	V	Ti	Tl	F
<b>Somers</b>										
Beef dairy nuts	2.9	5.6	1.2	0.24	0.02	<2	2.1	14.2	<0.1	58
Beef nuts	1.3	5.6	1.2	0.24	0.02	<2	2.1	14.2	<0.1	44
Calf nuts	<1.0	2.0	2.0	0.13	0.01	<2	1.1	5.90	<0.1	40
<b>Ryan</b>										
Beef dairy nuts	1.8	1.9	<.5	0.28	0.02	<2	2.7	14.1	<0.1	78

**Appendix 16.4:** The Phosphorus (P), Magnesium (Mg), Sodium (Na), Calcium (Ca) content (%), and Copper (Cu), Zinc (Zn), Cobalt (Co), Iodine (I), Selenium (Se) and Fluorine (F) content (mg kg<sup>-1</sup>) found for mineral mixes together with manufacturers certified values.

		P	Mg	Na	Ca	Cu	Zn	Co	I	Se	F
		g kg <sup>-1</sup>				mg kg <sup>-1</sup>					
Somers Dairy mix	found certified	0.0 0.0	110 100	247 300	0 0	3890 5000	4597 5000	226 200	700 750	60 70	280
Calf/beef mix	found certified	2.9 3.0	0 0	108 150	187 200	4347 5000	4045 5000	4045 5000	640 650	67 70	350
Ryan Dairy mix	found certified	0.0 0.0	107 100	256 300	0 0	4768 5000	3810 5000	194 200	620 750	71 70	175

**Appendix 16.5:** The Chromium (Cr), Lead (Pb), Manganese (Mn), Iron (Fe), Nickel (Ni), Cadmium (Cd), Vanadium (V), Titanium (Ti) and Thallium (Tl) content(mg kg<sup>-1</sup>) of the Mineral Mixes from the Somers and Ryans Farms

	<b>Cr</b>	<b>Pb</b>	<b>Mn</b>	<b>Fe</b>	<b>Ni</b>	<b>Cd</b>	<b>V</b>	<b>Ti</b>	<b>Tl</b>
<b>Somers</b>									
Dairy Mix	4.4	6.4	138	7490	12.8	0.18	11.9	61.7	<0.1
Calf/beef Mix	20.6	12.2	159	2395	13.0	1.80	29.5	59.2	<0.1
<b>Ryan</b>									
Dairy Mix	4.0	6.4	194	5580	20.1	0.44	11.9	71.6	<0.1



## APPENDIX 17

### Feed Quality Analysis of Silage Samples from the Somers, Ryan and Control farms - Sampled - May 1995

#### Appendix 17.1: Somers - Baled - 1st Cut

Test	Results	Comment
Dry matter (DM)	290 g kg <sup>-1</sup>	Dry
pH	4.8	Bad preservation
Digestibility (DMD)	590 g kg <sup>-1</sup> DM	Very poor quality
Crude Protein	141 g kg <sup>-1</sup> DM	Medium
Ash	94 g kg <sup>-1</sup> DM	Normal
Ammonia N/Total N (g kg <sup>-1</sup> )	139	Slightly High
Lactic Acid	19 g kg <sup>-1</sup> DM	
Estimated metabolisable energy (M.E.)	9.0 MJ kg <sup>-1</sup> DM	

#### Appendix 17.2: Somers - Pit Face - 1st Cut

Test	Results	Comment
Dry matter (DM)	194 g kg <sup>-1</sup>	Average
pH	4.0	Normal pH, Well preserved
Digestibility (DMD)	677 g kg <sup>-1</sup> DM	Medium quality
Crude Protein	153 g kg <sup>-1</sup> DM	Medium
Ash	88 g kg <sup>-1</sup> DM	Normal
Ammonia N/Total N (g kg <sup>-1</sup> )	82	Satisfactory
Lactic Acid	26 g kg <sup>-1</sup> DM	
Estimated metabolisable energy (M.E.)	10.0 MJ kg <sup>-1</sup> DM	

#### Appendix 17.3: Somers - Pit - 2nd Cut

Test	Results	Comment
Dry matter (DM)	198 g kg <sup>-1</sup>	Average
pH	3.9	Normal pH, Well preserved
Digestibility (DMD)	624 g kg <sup>-1</sup> DM	Poor quality
Crude Protein	134 g kg <sup>-1</sup> DM	Medium
Ash	98 g kg <sup>-1</sup> DM	Normal
Ammonia N/Total N (g kg <sup>-1</sup> )	57	Satisfactory
Lactic Acid	65 g kg <sup>-1</sup> DM	
Estimated metabolisable energy (M.E.)	9.4 MJ kg <sup>-1</sup> DM	

**Appendix 17.4: Ryan - Baled - House Side 1st Cut**

Test	Results	Comment
Dry matter (DM)	328 g kg <sup>-1</sup>	Dry
pH	4.9	Bad preservation
Digestibility (DMD)	637 g kg <sup>-1</sup> DM	Poor quality
Crude Protein	168 g kg <sup>-1</sup> DM	High
Ash	99 g kg <sup>-1</sup> DM	Normal
Ammonia N/Total N (g kg <sup>-1</sup> )	174	Too high
Lactic Acid	22 g kg <sup>-1</sup> DM	
Estimated metabolisable energy (M.E.)	9.5 MJ kg <sup>-1</sup> DM	

**Appendix 17.5: Ryan - Baled - Road Side 1st Cut**

Test	Results	Comment
Dry matter (DM)	298 g kg <sup>-1</sup>	Dry
pH	5.1	Bad preservation
Digestibility (DMD)	575 g kg <sup>-1</sup> DM	Very poor quality
Crude Protein	123 g kg <sup>-1</sup> DM	Medium
Ash	82 g kg <sup>-1</sup> DM	Normal
Ammonia N/Total N (g kg <sup>-1</sup> )	233	Excessively high
Lactic Acid	14 g kg <sup>-1</sup> DM	
Estimated metabolisable energy (M.E.)	8.9 MJ kg <sup>-1</sup> DM	

**Appendix 17.6: Control - Pit - 1st Cut**

Test	Results	Comment
Dry matter (DM)	226 g kg <sup>-1</sup>	Average
pH	3.7	Low pH, Well preserved
Digestibility (DMD)	658 g kg <sup>-1</sup> DM	Medium quality
Crude Protein	164 g kg <sup>-1</sup> DM	High
Ash	81 g kg <sup>-1</sup> DM	Normal
Ammonia N/Total N (g kg <sup>-1</sup> )	80	Satisfactory
Lactic Acid	78 g kg <sup>-1</sup> DM	
Estimated metabolisable energy (M.E.)	9.8 MJ kg <sup>-1</sup> DM	

**Appendix 17.7: Control - Pit - 1st Cut**

Test	Results	Comment
Dry matter (DM)	214 g kg <sup>-1</sup>	Average
pH	3.9	Normal pH, Well preserved
Digestibility (DMD)	671 g kg <sup>-1</sup> DM	Medium quality
Crude Protein	167 g kg <sup>-1</sup> DM	High
Ash	89 g kg <sup>-1</sup> DM	Normal
Ammonia N/Total N (g kg <sup>-1</sup> )	100	Slightly high
Lactic Acid	101 g kg <sup>-1</sup> DM	
Estimated metabolisable energy (M.E.)	9.9 MJ kg <sup>-1</sup> DM	

**Appendix 17.8: Recommended Quality Values for Unwilted Silage**

Dry Matter (DM)	180 - 230 g kg <sup>-1</sup>
pH	3.9 - 4.1
Digestibility (DMD)	650 - 730 g kg <sup>-1</sup> DM
Crude Protein (C.P.)	130 - 170 g kg <sup>-1</sup> DM
Ash	60 - 100 g kg <sup>-1</sup> DM
Ammonia N/Total N	60 - 100 g kg <sup>-1</sup>
Lactic Acid	60 - 120 g kg <sup>-1</sup> DM

## APPENDIX 18

### Mineral Analysis of Silage Samples from the Somers, Ryan and Control Farms

**Appendix 18.1:** The nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), sodium (Na), calcium (Ca) and sulphur content ( $\text{g kg}^{-1}$ ) of the herbage on the Somers farm

		N	P	K	Mg	Na	Ca	S
Somers	Baled	18.2	2.9	16.2	1.8	6.4	7.3	3.2
	Pit face	21.9	2.6	20.0	1.6	3.1	6.2	6.4
	Pit - 2nd Cut	16.2	2.5	18.3	1.6	4.5	6.8	3.9
Ryan	Baled house side	22.2	3.1	24.7	1.8	2.4	4.9	3.4
	Baled road side	18.0	3.0	21.6	1.7	5.1	4.6	2.8
Control	Pit face	21.6	2.5	18.5	1.8	5.0	5.6	3.5
	Pit face	21.4	2.5	20.8	1.9	5.1	5.1	4.8

**Appendix 18.2:** The manganese (Mn), copper (Cu), molybdenum (Mo), zinc (Zn), selenium (Se) and iodine content ( $\text{mg kg}^{-1}$ ) of the silage samples from the Somers, Ryan and O'Brien farms

		Mn	Cu	Mo	Zn	Se	I
Somers	Baled	152	9.5	0.65	32.1	0.05	0.10
	Pit face	108	21.1	1.55	26.7	0.17	0.13
	Pit - 2nd Cut	131	10.0	1.15	26.8	0.07	0.09
Ryan	Baled house side	169	12.3	0.75	32.7	0.06	0.12
	Baled road side	344	12.1	0.85	38.7	0.05	0.09
Control	Pit face	216	10.0	1.10	26.3	0.04	0.09
	Pit face	207	9.9	0.35	29.4	0.04	0.11

**Appendix 18.3:** The cadmium (Cd), lead (Pb), tin (Sn), thallium (Tl), arsenic (As) and mercury (Hg) content ( $\text{mg kg}^{-1}$ ) of the silage samples from the Somers, Ryan and O'Brien farms

		Cd	Pb	Sn	Tl	As	Hg
Somers	Baled	0.13	1.26	<1	<.05	0.30	0.002
	Pit face	0.09	1.61	<1	<.05	0.98	0.008
	Pit - 2nd Cut	0.08	0.66	<1	<.05	0.13	0.002
Ryan	Baled house side	0.20	1.42	<1	<.05	0.68	0.012
	Baled road side	0.15	1.16	<1	<.05	0.23	0.004
Control	Pit face	0.11	1.27	<1	<.05	0.68	0.016
	Pit face	0.10	1.21	<1	<.05	0.58	0.012

## APPENDIX 19

### Mineral Analysis of Hay Samples From Somers and Ryan Farms

**Appendix 19.1:** The Nitrogen (N), Phosphorus (P), Potassium (K), Magnesium (Mg), Sodium (Na), Calcium (Ca) and Sulphur (S) content ( $\text{g kg}^{-1}$ ) of the hay samples from the Somers and Ryan Farms

	N	P	K	Mg	Na	Ca	S
Somers	16.8	2.6	21.4	1.5	3.8	4.3	3.2
Ryans	12.5	1.6	6.7	1.6	4.4	6.7	4.9

**Appendix 19.2:** The Manganese (Mn), Copper (Cu), Molybdenum (Mo), Zinc (Zn), Iron (Fe), Selenium (Se) and Iodine (I) content ( $\text{mg kg}^{-1}$ ) of the hay samples from the Somers and Ryan Farms

	Mn	Cu	Mo	Zn	Fe	Se	I
Somers	104	9.7	1.45	38.8	89	0.10	0.11
Ryan	220	6.8	1.70	28.6	444	0.07	0.13

**Appendix 19.3:** The Cadmium (Cd), Chromium (Cr), Lead (Pb), Nickel (Ni), Tin (Sn), Aluminium (Al), Titanium (Ti), Vanadium (V), Thallium (Tl), Arsenic (As), Mercury (Hg) and Fluorine (F) content ( $\text{mg kg}^{-1}$ ) of the hay samples from the Somers and Ryan Farms

	Cd	Cr	Pb	Ni	Sn	Al	Ti	V	Tl	As	Hg	F
Somers	0.08	0.2	0.87	1.3	<1	159	26	0.71	<.05	0.05	0.006	9.2
Ryan	0.17	0.66	1.75	1.2	<1	518	54	5.18	<0.5	0.55	0.002	11.4

## APPENDIX 20

### Silage composition (g kg<sup>-1</sup>) 1996 and 1997

		pH	DMD	DM	CP	LA	NH <sub>4</sub> N %	N	P	K	Mg	Ca	Mn (mg kg <sup>-1</sup> )	Se (mg kg <sup>-1</sup> )
<b>Somers</b>	1 <sup>st</sup> Cut, 1996	4.0	648	271	147	45.2	3.5	19.8	3.0	22.6	1.5	5.3	71	0.10
	2 <sup>nd</sup> Cut, Bag, 1996	4.4	699	313	185	36.0	4.0	28.0	3.8	23.5	1.9	7.1	90	0.05
	1 <sup>st</sup> Cut, Bag, 1997	3.4	674	193	132	32.0	1.1	17.1	2.4	23.5	1.1	4.9	50	0.06
	2 <sup>nd</sup> Cut, 1997	4.7	659	320	164	-	-	21.7	4.1	29.8	2.1	6.3	200	0.08
<b>Ryan</b>	1996	3.7	712	237	144	63.7	2.9	23.9	3.2	19.8	2.1	7.0	148	0.04
	1 <sup>st</sup> Cut, 1997	4.4	636	238	158	41.6	5.2	20.9	3.7	33.8	1.7	6.7	114	0.04
	2 <sup>nd</sup> Cut, 1997	4.2	739	267	150	13.7	1.9	18.7	3.5	27.8	1.9	8.8	211	0.05
	1 <sup>st</sup> Cut, Bag, 1997	3.8	739	233	169	31.0	3.0	24.6	3.4	26.8	1.7	6.5	71	0.03
	2 <sup>nd</sup> Cut, Bag, 1997	4.0	663	259	184	47.0	3.6	19.7	3.1	22.9	1.9	5.4	205	0.03

## APPENDIX 21

### Appendix 21.1: Longitudinal Study. Soil Composition - July 1997

Farm	Crop	pH	Extractable (mg l <sup>-1</sup> )					
			P	K	Mg	Cu	Zn	Mn
LS 2	<sup>1</sup> P	6.6	3.2	41	191	8.1	7.7	600
	<sup>2</sup> P	6.5	3.7	49	189	11.7	7.2	398
	S	6.9	10.1	51	243	8.8	10.8	416
	S	6.4	3.5	42	207	6.3	6.4	512
LS 3	P	5.9	3.4	300	263	4.4	6.7	300
	P	6.1	2.4	240	192	6.8	4.7	364
	S	7.4	3.1	86	444	1.8	4.7	165
	S	7.4	2.1	68	400	2.0	4.8	157
LS 5	P	6.6	6.3	88	303	6.0	10.9	296
	S	5.9	2.6	52	255	3.4	4.5	171

<sup>1</sup>P, pasture; <sup>2</sup>S, silage

**Appendix 21.2:** Longitudinal Study. Soil Composition - July 1997

Farm	Crop	Total (mg kg <sup>-1</sup> )									
		Cu	Zn	Mn	Co	Se	F	Pb	Ni	Cd	Cr
LS 2	P	26.5	136.7	1475	13.5	0.80	700	68.6	48.7	1.55	30.3
	P	30.8	138.8	1428	15.6	0.45	760	54	46.2	1.48	30
	S	28.3	141.9	1486	13.7	0.70	780	80.2	47	1.76	28.4
	S	26.3	124.8	1379	13.8	0.75	590	110.5	46.6	1.48	30.5
LS 3	P	14.2	98.4	1112	10.3	0.50	660	58.5	24.2	0.31	21.8
	P	19.4	95	1176	10.8	0.50	490	75.2	23.6	0.34	19.9
	S	14.5	90.3	80.6	10.5	0.60	330	108.8	35.3	0.4	24.9
	S	15.4	92.3	785	9.8	0.60	430	52.2	35.2	0.41	25.5
LS 5	P	17.4	98.2	1379	8.9	0.45	430	63.2	42.2	0.92	28.0
	S	13.4	98.4	787	14.3	0.85	600	85.6	39.1	0.40	47.4



**Appendix 21.3:** Longitudinal Study. Herbage Composition - July 1997

Farm	N	<-----Extractable (mg l <sup>-1</sup> ) ----->					
		P	K	Mg	Na	Ca	S
LS 2	40.4	4.6	20.2	2.5	4.8	7.5	1.9
	35.2	4.1	18.0	2.2	5.2	7.2	2.6
	43.8	4.1	23.8	2.2	4.6	7.4	2.6
	43	3.7	17.7	2.7	6.0	9.2	3.0
LS 3	48.8	3.4	35.3	2.7	3.3	8.0	3.4
	42.8	3.4	35.4	2.5	4.8	5.9	3.7
	18.0	4.0	27.1	1.2	0.8	5.6	3.0
	23.9	4.2	31.2	1.6	1.4	7.7	3.8
LS 5	26.5	4.0	30.9	2.1	2.6	7.3	2.8
	29.8	3.5	11.7	2.9	7.1	8.3	4.7

**Appendix 21.4:** Longitudinal Study. Herbage Composition - July 1997

Farm	mg kg <sup>-1</sup>								
	Se	Mn	Zn	Cu	Mo	Ni	Cr	Pb	Cd
LS 2	0.07	147	45.5	11.6	2.7	1.64	0.15	0.43	0.13
	0.09	187	45.4	11.4	1.4	3.04	0.18	0.31	0.14
	0.08	45	38.4	10.6	2.4	1.09	0.29	0.40	0.08
	0.06	83	43.3	11.6	1.6	1.57	0.20	0.34	0.13
LS 3	0.07	128	48.4	12.4	0.6	1.26	0.40	0.37	0.08
	0.04	85	28.6	11.6	0.6	1.00	0.24	0.44	0.03
	0.05	8	37.1	5.9	1.4	1.60	0.05	0.13	0.02
	0.05	20	30.3	14.0	1.4	1.27	0.18	0.12	0.03
LS 5	0.05	38	36.2	7.8	3.3	5.74	0.15	0.44	0.13
	0.05	201	50.4	12.2	0.8	3.28	0.21	0.22	0.16

## APPENDIX 22

### Appendix 22.1: Longitudinal Study - Soil Composition - November 1997

Farm	Crop	pH	P	Extractable (mg l <sup>-1</sup> )			Zn	Total (mg kg <sup>-1</sup> )		F
				K	Mg	Cu		Mn	Co	
LS 1	P	6.6	8.5	110	268	8.1	9.3	1447	11.9	580
	S	6.2	4.5	50	160	4.8	5.9	1280	10.5	490
LS 2	P	6.6	2.5	22	176	6.2	5.3	1789	14.0	720
	P	6.8	2.1	22	223	8.0	8.4	1666	13.8	600
	S	6.7	2.5	32	209	11.7	11.6	1671	16.1	660
	S	6.8	5.0	27	230	6.6	8.1	1734	13.0	600
LS 3	P	5.8	2.4	187	219	5.8	6.7	1103	10.4	580
	P	5.9	2.0	234	272	3.4	7.0	1203	10.0	490
	S	7.3	1.2	42	419	2.0	4.7	802	10.2	360
	S	7.4	2.1	78	316	2.0	6.3	801	10.1	360
LS 5	P	6.8	5.4	76	292	4.9	8.4	1025	10.9	540
	S	5.8	1.6	31	253	2.2	3.4	1304	15.8	540

### Appendix 22.2: Longitudinal Study. Herbage Composition (g kg<sup>-1</sup>) - November 1997

Farm	N	P	K	Mg	Na	Ca	S
LS 1	43.8	6.1	43.6	2.4	3.4	4.9	3.9
	23.1	2.4	14.9	2.0	3.7	5.7	2.6
LS 2	41.5	5.3	35.3	2.1	4.0	4.9	3.5
	37.7	5.7	42.2	2.1	4.4	4.6	3.4
	41.3	4.8	28.6	2.5	4.9	7.5	3.4
	36.7	4.3	20.4	2.5	9.2	6.3	3.2
LS 3	44.8	5.1	43.0	2.3	3.7	3.6	4.2
	44.8	5.2	40.1	2.6	2.3	4.0	4.0
	36.8	4.3	33.1	1.8	3.2	5.8	2.8
LS 5	35.8	5.4	47.1	2.2	4.2	5.5	3.5
	32.6	4.1	32.6	2.7	1.5	5.6	5.3

**Appendix 22.3:** Longitudinal Study. Herbage Composition (mg kg<sup>-1</sup>). November 1997

<b>Farm No</b>	<b>Crop</b>	<b>Se</b>	<b>Mn</b>	<b>Zn</b>	<b>Cu</b>	<b>Mo</b>
LS 1	P	0.16	118	40.0	10.1	3.3
	S	0.18	499	50.5	10.4	0.9
LS 2	P	0.14	122	38.5	10.5	2.6
	P	0.10	146	42.1	12.4	3.0
	S	0.09	33	28.9	8.5	2.3
	S	0.08	133	30.6	10.2	1.0
	P	0.06	108	33.9	10.6	1.9
LS 3	P	0.07	100	35.3	11.9	1.5
	S	0.09	93	26.8	8.0	4.3
	P	0.24	44	38.9	10.7	2.1
LS 5	S	0.08	186	48.8	11.7	0.5

## APPENDIX 23

**Appendix 23:** Longitudinal Study. Farm LS 1. Additional Soil Composition - November 1997

Component	Paddock	
	Grazing	Silage
Total cobalt (mg kg <sup>-1</sup> )	11.9	10.5
Total manganese (mg kg <sup>-1</sup> )	1447	1280
Total selenium (mg kg <sup>-1</sup> )	0.70	0.55
Total mercury (mg kg <sup>-1</sup> )	0.14	0.16
Total cadmium (mg kg <sup>-1</sup> )	1.47	1.27
Total fluorine (mg kg <sup>-1</sup> )	580	490

# APPENDIX 24

Appendix 24.1: Longitudinal Study - Silage composition (g kg<sup>-1</sup>)

Farm		pH	DMD	DM	<sup>1</sup> CP	<sup>2</sup> LA	<sup>3</sup> NH <sub>4</sub> N/ Total N	N	P	K	Mg	Na	Ca	S
LS 1	1996 – Cut 1	4.8	589	493	106	-	98	15.0	2.3	21.7	1.95	2.5	9.1	2.1
	1996 – Cut 2	5.6	592	447	133	18	104	18.5	2.9	11.1	2.50	5.9	11.0	1.4
	1996 – Hay	-	572	930	85	-	-	13.0	3.0	12.0	2.05	6.2	6.7	2.4
LS 2	1996 – Cut 1	3.8	689	199	148	81	31	21.0	2.4	13.9	1.95	4.9	7.5	3.3
	1996 – Cut 2	4.6	678	429	154	32	69	22.5	2.7	15.8	2.85	6.4	6.1	4.2
	1997	6.5	684	629	-	-	-	14.2	2.4	16.5	1.20	5.6	4.7	1.4
LS 3	1996 – Cut 1	3.9	659	193	157	84	118	21.4	3.1	29.7	1.60	2.2	6.8	2.3
	1996 – Cut 2	4.0	606	301	151	73	119	24.7	3.0	23.2	1.80	2.3	8.3	3.3
	1997	4.2	628	245	136	42	121	24.4	2.4	16.8	1.40	2.9	7.3	2.1
LS 5	1996 – Cut 1	4.2	703	182	151	-	-	18.8	3.3	26.1	2.00	4.0	6.8	1.9
	1996 – Cut 2	6.9	668	274	144	-	-	17.9	2.3	16.2	2.15	7.5	6.1	3.0
	1996 (off farm)	4.2	653	225	142	-	-	16.6	2.3	13.6	2.30	6.3	6.5	2.6
	1997	4.1	710	317	143	59	79	22.2	2.9	23.9	1.60	5.4	5.1	2.2

<sup>1</sup>Crude protein; <sup>2</sup>Lactic acid; <sup>3</sup>Ammonia N in total N

**Appendix 24.2: Longitudinal Study - Silage composition (mg kg<sup>-1</sup>)**

**TRACE ELEMENTS**

Farm		Se	Mn	Zn	Cu	Mo	Ni	Cr	Pb	Cd	I
LS 1	1996 – Cut 1	0.06	130	21.5	6.55	0.85					0.33
	1996 – Cut 2	0.06	69	22.0	6.70	1.60					0.16
	1996 – Hay	0.17	135	18.5	4.9	0.80					0.43
LS 2	1996 – Cut 1	0.15	76	26.0	10.9	1.10					0.10
	1996 – Cut 2	0.22	75	30.5	10.8	0.85					0.11
	1997	0.04	36	26.2	5.5	0.60	0.96	0.49	0.13	0.04	-
LS 3	1996 – Cut 1	0.04	27	25.5	7.3	1.9					0.30
	1996 – Cut 2	0.05	19	31.5	7.5	1.1					0.60
	1997	0.05	68	36.2	8.1	1.2	1.31	1.04	0.74	0.16	-
LS 5	1996 – Cut 1	0.10	80	28.5	8.4	1.2					0.31
	1996 – Cut 2	0.05	212	33.0	9.3	1.2					0.22
	1996 (off farm)	0.08	132	31.0	9.8	1.5					0.18
	1997	0.05	82	31.4	6.4	1.0	1.70	0.77	0.36	0.04	-

## APPENDIX 25

**Appendix 25.1:** Retrospective Study. Extractable Components of Soil (mg l<sup>-1</sup>) and pH - July 1997

Farm No.	Crop	pH	P	K	Mg	Cu	Zn	Mn
6	P	6.6	3.2	41	191	8.1	7.7	00
	P	6.5	3.7	49	189	11.7	7.2	398
	S	6.9	10.1	51	243	8.8	10.8	416
7	S	6.4	3.5	42	207	6.3	6.4	512
	P	5.9	3.4	300	263	4.4	6.7	300
	P	6.1	2.4	240	192	6.8	4.7	364
9	S	7.4	3.1	86	444	1.8	4.7	165
	S	7.4	2.1	6.8	400	2.0	4.8	157
	P	6.6	6.3	88	303	6.0	10.9	296
14	S	5.9	2.6	52	255	3.4	4.5	171
	P	6.8	3.2	121	164	6.5	3.5	140
15	S	5.6	4.0	52	90	3.3	4.0	79
	P	5.9	7.4	224	165	5.1	5.2	214
16	S	6.0	5.4	101	325	15.1	11.3	120
	P	5.9	3.9	89	136	20.4	13.3	263
17	S	5.8	10.8	161	154	9.0	7.5	189
	P	6.1	3.0	99	262	4.4	7.0	400
18	S	6.9	9.0	40	275	6.6	9.3	286
	P	6.1	1.5	97	126	10.6	4.4	363
19	S	6.1	5.6	74	111	5.6	4.9	605
	P	6.0	10.0	156	229	5.2	6.7	446
20	S	6.2	2.3	74	149	3.4	6.3	471
	P	6.8	17.7	250	291	9.5	13.9	383
21	S	5.8	4.0	72	93	4.0	7.2	239
	P	5.9	3.8	149	110	3.0	7.1	198
22	S	5.9	3.9	53	114	11.1	10.3	265
	P	6.3	16.0	63	191	19.8	15.2	214
23	S	6.3	2.8	59	147	5.9	5.1	334
	P	6.5	3.5	94	154	4.4	5.1	397
24	S	6.3	4.5	118	90	6.9	5.2	250
	P	5.6	3.9	58	86	4.5	21.5	156
25	S	6.0	5.4	69	253	3.7	6.5	161
	P	7.4	8.0	27	684	1.2	17.1	62
26	S	6.8	4.7	61	333	4.9	8.9	398
	P	6.6	8.6	27	343	4.5	8.7	426
27	S	5.9	3.6	196	123	3.3	5.2	307
	P	5.7	4.5	115	102	2.2	4.4	301
28	S	5.9	6.3	134	170	8.2	7.8	278
	P	6.0	4.8	78	128	5.0	5.9	181
29	S	6.4	9.5	194	184	6.9	10.4	382
	P	6.3	5.6	54	123	8.2	8.6	459
30	S	6.3	18.7	300	238	3.9	11.7	492
	P	6.1	7.9	71	127	2.8	5.8	473
31	S	6.1	5.9	150	141	2.9	6.3	429
	P	6.6	2.2	56	112	2.4	3.7	505
	S	6.6	9.9	207	168	20.7	11.1	232
	P	6.2	6.0	107	145	9.7	8.6	246
Mean		6.3	5.9	108	203	6.7	7.9	315
SD		0.5	3.9	70	112	4.6	3.7	138
Min		5.6	1.5	27	86	1.2	3.5	62
Max		7.4	18.7	300	684	20.7	21.5	605

P = Pasture, S Silage ground

**Appendix 25.2: Retrospective Study. Soil Composition (mg kg<sup>-1</sup>) - July 1997**

Farm No.	Cu	Zn	Mn	Co	Se	F	Pb	Ni	Cd	Cr
6	26.5	136.7	1475	13.5	0.80	700	68.6	48.7	1.55	30.3
	30.8	138.8	1428	15.6	0.45	760	54.0	46.2	1.48	30.0
	28.3	141.9	1486	13.7	0.70	780	80.2	47.0	1.76	28.4
	26.3	124.8	1379	13.8	0.75	590	110.5	46.6	1.48	30.5
7	14.2	98.4	1112	10.3	0.50	660	58.5	24.2	0.31	21.8
	19.4	95.0	1176	10.8	0.50	490	75.2	23.6	0.34	19.9
	14.5	90.3	81	10.5	0.60	330	108.8	35.3	0.40	24.9
	15.4	92.3	785	9.8	0.60	430	52.2	35.2	0.41	25.5
9	17.4	98.2	1379	8.9	0.45	430	63.2	42.2	0.92	28.0
	13.4	98.4	787	14.3	0.85	600	85.6	39.1	0.40	47.4
14	17.9	72.5	445	7.1	1.40	820	29.8	32.5	0.46	26.7
	12.1	67.5	188	4.5	0.90	820	20.3	26.4	0.34	26.9
15	23.7	107.7	582	13.0	1.20	800	19.0	43.7	1.39	39.1
	56.4	95.7	399	10.5	14.5	620	25.3	45.7	4.04	40.1
16	50.9	126.4	790	11.8	2.85	620	44.9	45.8	2.19	25.5
	35.5	76.6	415	4.3	2.50	490	27.9	22.3	1.23	23.4
17	21.6	164.7	1279	13.0	0.85	860	40.0	45.9	1.49	31.6
	22.3	139.7	1193	10.9	0.85	800	56.9	41.0	1.41	26.3
18	27.8	107.3	946	9.2	0.85	900	91.3	37.5	0.69	25.4
	17.6	118.4	1340	8.9	0.70	740	103.8	30.9	0.63	21.3
19	19.8	106.1	1398	11.1	0.70	620	51.8	42.9	1.53	23.5
	18.3	163.4	1138	10.5	0.75	620	96.2	44.9	1.32	23.6
20	25.8	125.4	1614	9.3	0.70	580	124.2	38.9	1.54	21.9
21	13.8	81.3	416	7.6	0.45	590	39.5	23.0	0.34	17.8
	11.8	88.2	482	7.0	0.45	600	45.1	23.9	0.37	17.8
22	20.1	46.4	644	3.4	0.45	350	79.6	10.9	0.20	11.5
	33.6	64.8	494	4.9	0.60	490	48.3	17.3	0.25	13.5
23	21.9	144.4	1431	13.7	0.90	760	87.3	48.3	1.97	28.4
	18.1	119.1	1333	13.5	0.95	800	65.4	42.9	1.61	26.8
24	17.1	97.3	722	7.7	0.60	860	39.9	29.2	0.46	21.4
	18.8	376.7	458	9.3	0.65	860	221.9	38.6	1.47	29.8
25	15.2	98.1	822	13.6	0.75	860	42.5	33.0	0.87	31.4
	16.4	111.8	1289	12.4	0.60	350	59.2	35.5	1.13	25.0
26	15.1	122.1	306	6.2	1.35	600	28.5	27.2	0.79	10.8
	18.9	116.4	1466	11.5	0.60	760	35.3	36.9	1.16	26.7
	11.6	83.4	980	11.5	0.40	860	31.9	23.7	0.31	17.0
	11.7	79.6	863	9.2	0.50	800	17.1	21.0	0.29	18.6
27	22.1	103.6	805	9.0	0.45	740	34.0	29.1	0.54	24.3
	14.4	77.4	531	9.3	0.45	940	27.9	30.8	0.39	25.2
28	20.0	148.0	1261	11.6	0.65	600	43.0	46.1	1.54	22.6
	21.3	136.4	1158	10.4	0.60	600	39.2	39.4	1.45	24.6
29	15.3	190.2	1687	13.5	0.50	700	44.2	50.4	1.81	26.8
	14.8	149.5	1680	11.6	0.50	640	45.1	40.5	1.60	25.3
30	13.7	135.2	1529	13.4	0.55	600	37.3	41.4	1.19	23.8
	15.3	160.8	2034	10.1	0.65	620	37.4	59.1	1.71	28.9
31	58.6	140.2	710	9.6	0.70	1070	789.0	34.3	0.56	24.2
	19.3	85.9	658	9.2	0.50	550	40.5	18.5	0.41	17.1
Mean	21.6	117.9	991	10.3	1.06	674	73.8	35.9	1.06	25.1
SD	10.6	49.1	464	2.8	2.06	164	112.5	10.4	0.73	6.7
Min	11.6	46.4	81	3.4	0.40	330	17.1	10.9	0.20	10.8
Max	58.6	376.7	2034	15.6	14.5	1070	789.0	59.1	4.04	47.4



**Appendix 25.3: Retrospective Study. Herbage Composition (g kg<sup>-1</sup>) - July 1997**

Farm	N	P	K	Mg	Na	Ca	S
6	40.4	4.6	20.2	2.5	4.8	7.5	1.9
	35.2	4.1	18.0	2.2	5.2	7.2	2.6
	43.8	4.1	23.8	2.2	4.6	7.4	2.6
	43.0	3.7	17.7	2.7	6.0	9.2	3.0
7	48.8	3.4	35.3	2.7	3.3	8.0	3.4
	42.8	3.4	35.4	2.5	4.8	5.9	3.7
	18.0	4.0	27.1	1.2	0.8	5.6	3.0
	23.9	4.2	31.2	1.6	1.4	7.7	3.8
9	26.5	4.0	30.9	2.1	2.6	7.3	2.8
	29.8	3.5	11.7	2.9	7.1	8.3	4.7
14	24.5	3.8	20.6	1.9	3.1	8.0	3.0
	18.2	2.7	13.5	2.4	7.5	7.6	3.3
15	34.0	4.6	32.5	1.9	1.7	4.9	3.0
	21.4	3.7	21.4	2.3	3.5	6.7	3.0
16	17.8	3.5	20.9	1.6	2.2	6.3	3.1
	36.2	4.7	27.7	2.2	3.2	5.6	3.2
17	31.2	3.7	27.2	2.3	3.0	7.5	3.0
	42.6	4.9	24.4	2.2	5.7	6.3	2.8
18	35.0	3.3	26.5	2.5	3.4	7.6	3.0
	42.3	4.7	26.4	2.6	4.5	9.9	3.0
19	29.1	4.3	26.0	2.2	3.1	9.2	3.0
	26.8	2.9	16.3	2.6	4.3	12.7	2.0
20	48.7	5.7	30.1	2.3	1.5	10.3	3.1
	25.5	4.2	27.1	2.3	2.3	6.2	3.0
21	29.9	3.9	30.9	2.1	1.8	5.5	3.5
	28.6	4.0	14.8	2.5	5.1	6.9	2.5
22	12.6	2.7	18.8	1.5	2.5	6.4	1.6
	36.6	4.1	24.3	2.3	5.3	9.6	2.6
23	26.4	3.7	20.9	2.0	3.5	8.6	2.8
	48.6	4.3	33.5	2.5	3.3	13.3	3.9
24	41.2	4.4	34.8	1.7	1.2	5.7	3.8
	34.7	5.9	24.2	2.8	4.0	7.3	3.8
25	19.8	3.5	20.6	2.0	3.0	9.1	2.7
	24.3	4.7	16.9	2.6	6.8	8.0	2.6
26	26.5	3.9	15.8	3.0	7.0	9.7	3.0
	31.5	3.5	32.5	2.2	1.2	6.6	3.4
27	22.6	3.2	27.2	2.1	2.1	5.9	3.1
	47.7	2.6	29.5	1.9	5.1	5.0	3.0
28	47.6	2.7	21.7	3.0	6.7	8.9	3.6
	44.1	4.3	34.4	2.2	2.9	7.5	3.1
29	19.7	3.9	19.5	1.9	4.5	6.9	2.7
	37.4	5.2	34.0	2.1	1.2	8.0	3.0
30	29.4	4.7	18.6	2.1	5.5	7.0	2.0
	17.0	3.1	18.8	1.6	2.1	5.4	2.0
31	17.4	3.1	21.6	1.8	5.5	8.6	1.0
	33.8	3.9	34.1	2.0	2.6	5.5	2.6
	39.2	4.3	30.3	2.1	2.9	5.7	3.6
Mean	32.0	3.9	24.9	2.2	3.7	7.5	3.0
SD	10.1	0.7	6.6	0.4	1.8	1.8	0.6
Min	12.6	2.6	11.7	1.2	0.8	4.9	1.0
Max	48.8	5.9	35.4	3.0	7.5	13.3	4.7

**Appendix 25.4: Retrospective Study. Herbage Composition (mg kg<sup>-1</sup>) - July 1997**

Farm No.	Se	Mn	Zn	Cu	Mo	Ni	Cr	Pb	Cd
6	0.07	147	45.5	11.6	2.7	1.64	0.15	0.43	0.13
	0.09	187	45.4	11.4	1.4	3.04	0.18	0.31	0.14
	0.08	45	38.4	10.6	2.4	1.09	0.29	0.40	0.08
7	0.06	83	43.3	11.6	1.6	1.57	0.20	0.34	0.13
	0.07	128	48.4	12.4	0.6	1.26	0.40	0.37	0.08
	0.04	85	28.6	11.6	0.6	1.00	0.24	0.44	0.03
	0.05	8	37.1	5.9	1.4	1.60	0.05	0.13	0.02
	0.05	20	30.3	14.0	1.4	1.27	0.18	0.12	0.03
9	0.05	38	36.2	7.8	3.3	5.74	0.15	0.44	0.13
	0.05	201	50.4	12.2	0.8	3.28	0.21	0.22	0.16
14	0.54	239	32.2	9.2	1.5	3.49	0.60	0.59	0.13
	0.35	256	24.1	7.4	0.6	2.17	0.20	0.17	0.11
15	0.11	206	36.0	9.9	3.4	3.23	0.29	0.15	0.19
	4.90	134	37.6	9.5	3.9	2.57	0.57	0.55	0.41
16	0.40	218	27.0	6.2	6.7	3.37	0.25	0.47	0.17
	0.18	340	46.3	11.4	17.0	2.63	0.68	0.44	0.53
17	0.06	118	31.1	9.7	1.7	1.93	0.30	0.39	0.06
	0.18	48	50.7	12.4	1.8	1.30	0.21	0.25	0.08
18	0.09	155	36.0	11.8	0.4	2.00	0.45	0.59	0.15
	0.16	258	31.1	10.6	1.9	3.94	0.14	0.29	0.23
19	0.05	32	29.6	8.1	3.9	0.83	0.23	0.11	0.03
	0.08	93	39.3	11.1	2.0	1.34	0.33	0.57	0.15
20	0.07	82	43.9	12.6	3.4	2.36	1.02	1.93	0.07
21	0.06	517	32.5	8.4	0.9	1.03	0.25	0.34	0.05
	0.05	309	38.6	9.4	0.7	5.12	0.60	0.67	0.07
22	0.12	224	42.0	11.2	0.9	3.23	0.44	1.21	0.07
	0.15	91	20.0	6.4	2.9	0.77	0.12	0.48	0.04
23	0.12	80	29.6	11.5	8.4	2.17	0.20	0.31	0.11
	0.07	96	29.4	8.4	2.7	1.24	0.46	1.56	0.17
24	0.09	127	33.6	12.9	0.5	3.52	0.20	0.73	0.06
	0.08	154	236.2	12.6	0.8	2.54	0.12	4.00	1.66
25	0.05	175	32.1	10.2	1.9	1.45	0.76	1.05	0.12
	0.08	53	33.2	6.4	4.1	0.47	0.04	0.10	0.11
	0.03	32	27.8	8.5	0.6	0.67	0.26	0.52	0.04
	0.05	85	28.4	10.0	0.5	1.25	0.05	0.12	0.19
26	0.04	109	24.6	9.7	1.2	3.01	0.23	0.33	0.02
	0.03	331	27.4	7.7	0.3	4.82	0.11	0.22	0.09
27	0.04	113	32.7	12.6	0.4	2.51	0.42	0.48	0.08
	0.11	119	40.6	15.2	0.3	3.61	0.78	0.63	0.18
28	0.05	66	34.3	12.6	1.3	2.16	0.46	0.36	0.13
	0.16	131	30.9	8.4	1.2	1.88	0.84	0.51	0.25
29	0.03	90	48.4	9.0	2.0	1.22	0.31	0.47	0.11
	0.03	155	47.2	7.8	0.5	2.93	0.63	0.75	0.46
30	0.06	389	33.0	6.8	0.9	2.81	0.78	0.65	0.18
	0.03	64	23.5	6.9	1.4	1.78	0.49	0.44	0.08
31	0.06	67	48.7	10.6	2.1	2.11	0.25	3.43	0.07
	0.09	155	49.5	12.0	1.6	1.67	1.10	1.17	0.11
Mean	0.20	146	40.3	10.1	2.2	2.27	0.37	0.64	0.16
SD	0.71	105	30.3	2.3	2.7	1.19	0.26	0.75	0.25
Min	0.03	8	20.0	5.9	0.3	0.47	0.04	0.10	0.02
Max	4.90	517	236.2	15.2	17.0	5.74	1.10	4.00	1.66

Appendix 25.5: Retrospective Study. Silage Composition (g kg<sup>-1</sup>) - July 1997

Farm No.	pH	DMD	DM	<sup>1</sup> CP	<sup>2</sup> LA	<sup>3</sup> NH <sub>4</sub> N	N	P	K	Mg	Na	Ca	S
6*	6.5	684	629	-	-	-	14.2	2.4	16.5	1.2	5.6	4.7	1.4
7	4.2	628	245	136	42	121	24.4	2.4	16.8	1.4	2.9	7.3	2.1
9	4.1	710	317	143	59	79	22.2	2.9	23.9	1.6	5.4	5.1	2.2
14	4.7	657	411	136	16	43	16.4	2.3	20.9	1.8	4.4	5.6	2.0
15	4.0	650	329	108	47	39	16.5	1.9	13.8	1.7	4.5	7.8	1.2
16	3.9	639	320	114	47	70	17.2	2.3	12.4	1.5	5.8	6.5	1.8
17	3.7	708	226	129	102	68	19.6	2.3	16.2	2.0	5.0	7.2	1.9
18	3.9	633	328	127	52	81	10.8	1.9	14.9	1.3	2.3	4.5	1.4
19	4.0	717	300	121	66	54	17.9	2.3	22.6	1.7	4.3	7.3	1.3
20	4.3	610	425	88	23	44	14.0	1.9	12.5	1.6	3.9	6.2	1.7
21**	-	579	881	161	-	-	20.3	2.4	14.6	1.4	2.2	4.8	2.4
22	3.9	633	318	127	52	81	16.1	2.5	23.1	1.5	2.2	4.2	1.8
23	4.3	648	192	133	44	97	19.7	2.5	20.9	1.3	3.0	6.9	1.5
24	4.1	495	297	96	5	30	10.6	1.9	10.5	1.4	4.7	3.9	1.4
25	4.5	559	266	122	26	138	15.1	3.0	17.6	2.1	2.8	8.5	2.0
26	3.8	552	237	118	28	62	17.8	2.4	19.7	1.8	3.2	4.9	1.9
27	4.3	601	235	143	29	91	22.8	2.4	16.5	1.7	4.1	5.3	2.0
28	4.8	572	354	139	13	77	18.2	2.6	16.3	1.8	4.4	5.2	1.9
29	4.0	699	229	142	75	68	21.2	2.6	20.3	1.4	3.2	8.1	1.7
30	3.9	713	256	81	122	73	14.4	2.1	20.1	1.5	3.6	8.3	1.2
31	4.9	655	417	111	11	65	16.7	2.8	25.8	1.8	3.7	4.8	1.9
Mean	4.2	633.2	333.6	123.1	45.4	70.0	17.2	2.4	18.0	1.6	3.8	6.1	1.7
SD	0.4	67.1	152.0	21.8	32.6	26.4	3.5	0.3	4.4	0.2	1.0	1.5	0.3
Min	3.7	495.0	192.0	81.0	5.0	30.0	10.6	1.9	10.5	1.2	2.2	3.9	1.2
Max	4.9	717.0	881.0	161.0	122.0	138.0	24.4	3.0	25.8	2.1	5.8	8.5	2.4

<sup>1</sup>Crude Protein; <sup>2</sup>Lactic acid; <sup>3</sup>Ammonia N in total N

\*Not included in statistical analysis

\*\*Hay Sample

**Appendix 25.6: Retrospective Study. Silage Composition (mg kg<sup>-1</sup>) - July 1997**

<b>Farm No.</b>	<b>Se</b>	<b>Mn</b>	<b>Zn</b>	<b>Cu</b>	<b>Mo</b>	<b>Ni</b>	<b>Cr</b>	<b>Pb</b>	<b>Cd</b>
6	0.04	36	26.2	5.5	0.6	0.96	0.49	0.13	0.04
7	0.05	68	36.2	8.1	1.2	1.31	1.04	0.74	0.16
9	0.05	82	31.4	6.4	1.0	1.70	0.77	0.36	0.04
14	0.10	278	40.5	7.6	1.0	2.53	1.37	0.54	0.14
15	0.13	36	29.0	4.8	2.3	0.47	0.28	0.19	0.12
16	0.14	68	23.6	7.6	4.2	2.30	0.71	0.37	0.18
17	0.23	51	28.3	5.7	1.8	1.49	0.90	0.43	0.09
18	0.06	285	27.7	5.2	1.1	1.96	1.04	0.49	0.16
19	0.13	51	27.3	4.8	1.1	1.45	0.56	0.38	0.19
20	0.05	294	35.0	2.9	1.5	4.14	1.32	0.73	0.33
21	0.04	169	28.1	6.5	0.9	2.59	0.49	0.34	0.11
22	0.04	111	39.7	10.4	1.0	1.60	1.70	0.64	0.07
23	0.10	35	23.3	7.8	0.7	1.42	0.92	0.76	0.07
24	0.10	313	36.7	8.8	0.8	3.00	3.29	2.11	0.29
25	0.10	147	29.6	7.3	1.7	3.38	2.94	2.14	0.21
26	0.05	176	31.8	8.4	0.7	2.03	0.62	1.45	0.12
27	0.05	224	32.8	10.8	0.7	4.76	1.54	0.47	0.25
28	0.09	192	32.5	8.9	0.5	2.66	0.75	0.44	0.24
29	0.04	78	28.8	8.1	1.5	1.49	0.45	0.46	0.12
30	0.04	67	19.5	6.3	1.0	1.76	0.79	0.42	0.10
31	0.04	149	31.1	7.0	1.2	2.30	0.63	0.23	0.09
<b>Mean</b>	0.08	147.7	30.4	7.1	1.30	2.26	1.11	0.68	0.15
<b>SD</b>	0.05	96.9	5.9	2.2	0.85	1.10	0.82	0.59	0.08
<b>Min</b>	0.04	35.0	19.5	2.9	0.50	0.47	0.28	0.13	0.04
<b>Max</b>	0.23	313.0	40.5	10.8	4.20	4.76	3.29	2.14	0.33

**Appendix 25.7: Retrospective Study. Soil Composition - November 1997**

Farm No	Crop	pH	<-----Extractable (mg l <sup>-1</sup> ) ----->					Total (mg kg <sup>-1</sup> )		
			P	K	Mg	Cu	Zn	Mn	Co	F
5	P	6.6	8.5	110	268	8.1	9.3	1447	11.9	580
	S	6.2	4.5	50	160	4.8	5.9	1280	10.5	490
6	P	6.6	2.5	22	176	6.2	5.3	1789	14.0	720
	P	6.8	2.1	22	223	8.0	8.4	1666	13.8	600
	S	6.7	2.5	32	209	11.7	11.6	1671	16.1	660
	S	6.8	5.0	27	230	6.6	8.1	1734	13.0	600
7	P	5.8	2.4	187	219	5.8	6.7	1103	10.4	580
	P	5.9	2.0	234	272	3.4	7.0	1203	10.0	490
	S	7.3	1.2	42	419	2.0	4.7	802	10.2	360
	S	7.4	2.1	78	316	2.0	6.3	801	10.1	360
9	P	6.8	5.4	76	292	4.9	8.4	1025	10.9	540
	S	5.8	1.6	31	253	2.2	3.4	1304	15.8	540
14	P	6.4	2.0	60	161	7.7	5.7	497	9.9	800
	S	5.4	2.9	54	84	2.1	3.6	213	7.1	840
15	P	5.9	4.8	222	153	5.9	5.8	605	18.1	740
	S	6.2	3.6	64	318	17.1	8.6	408	14.7	740
16	P	5.9	3.6	40	126	20.9	11.3	737	14.5	660
	S	6.0	6.8	104	125	10.2	6.3	512	9.8	550
17	P	6.2	2.8	84	239	4.1	7.2	1123	11.9	840
	S	6.9	7.5	41	219	5.7	8.0	1167	12.6	640
18	P	6.1	1.2	28	106	10.3	5.3	955	10.0	660
	S	5.8	2.9	27	106	6.0	4.8	1175	9.6	560
19	P	7.1	11.3	160	245	5.6	9.8	1446	10.0	530
	S	6.4	2.7	89	154	3.2	5.6	622	11.6	370
20	P	6.9	12.5	172	260	8.7	13.3	1705	9.6	490
21	P	5.7	3.1	117	86	3.4	6.8	533	6.7	600
22	P	5.9	4.4	74	112	8.2	9.3	807	4.7	270
	S	6.4	12.8	67	189	16.9	16.0	655	4.7	410
23	P	6.8	3.4	57	138	5.3	5.4	1726	13.4	790
	S	6.5	2.4	42	121	3.3	3.6	1486	14.5	600
24	P	5.6	3.5	101	88	3.9	8.1	622	8.2	740
	S	5.8	3.7	78	111	4.3	16.0	436	10.0	920
25	P	5.9	6.5	65	306	3.7	5.7	543	8.6	740
	P	7.2	16.5	149	571	1.5	16.0	322	3.7	285
	S	6.9	12.1	20	363	5.3	16.0	1188	11.2	620
	S	6.3	7.5	22	295	4.0	8.5	1361	12.6	720
26	P	6.2	15.9	183	450	5.9	6.6	854	9.3	1010
	S	5.8	4.1	162	112	2.3	9.1	841	9.9	860
27	P	6.0	3.3	46	138	7.8	7.8	767	8.4	800
	S	5.6	1.9	37	106	3.5	4.8	1200	9.4	640
28	P	6.5	7.7	44	152	5.9	8.8	1215	13.2	620
	S	6.8	8.3	40	170	8.4	9.8	1125	13.6	680
29	P	6.1	8.0	155	197	3.2	9.3	1484	14.8	680
	S	6.0	7.6	33	122	3.0	5.6	1561	13.3	680
30	P	6.0	2.4	111	118	2.7	4.7	1406	13.2	620
	S	6.7	1.5	38	106	2.8	4.2	1782	16.6	720
31	P	6.5	5.3	78	174	12.8	12.9	709	9.8	630
	S	6.1	4.4	67	139	8.7	8.8	652	7.4	370
Mean		6.3	5.2	80	202	6.3	8.0	1047	11.1	623.9
SD		0.5	3.8	56	104	4.1	3.4	443	3.1	160.9
Min		5.4	1.2	20	84	1.5	3.4	213	3.7	270
Max		7.4	16.5	234	571	20.9	16.0	1789	18.1	1010

**Appendix 25.8:** Retrospective Study. Herbage Composition (g kg<sup>-1</sup>) - November 1997

Farm	No Crop	N	P	K	Mg	Na	Ca	S
5	P	43.8	6.1	43.6	2.4	3.4	4.9	3.9
	S	23.1	2.4	14.9	2.0	3.7	5.7	2.6
6	P	41.5	5.3	35.3	2.1	4.0	4.9	3.5
	P	37.7	5.7	42.2	2.1	4.4	4.6	3.4
	S	41.3	4.8	28.6	2.5	4.9	7.5	3.4
	S	36.7	4.3	20.4	2.5	9.2	6.3	3.2
7	P	44.8	5.1	43.0	2.3	3.7	3.6	4.2
	P	44.8	5.2	40.1	2.6	2.3	4.0	4.0
	S	36.8	4.3	33.1	1.8	3.2	5.8	2.8
9	P	35.8	5.4	47.1	2.2	4.2	5.5	3.5
	S	32.6	4.1	32.6	2.7	1.5	5.6	5.3
14	P	31.4	4.3	28.6	1.5	1.6	3.6	3.3
	S	33.4	4.6	29.0	2.3	3.9	4.1	2.3
15	P	31.2	4.1	29.6	2.0	2.4	2.8	2.4
	S	38.7	6.2	38.4	2.3	2.7	3.1	3.5
16	P	32.9	3.9	29.2	1.7	1.9	3.5	2.2
	S	38.9	6.6	49.8	2.5	2.7	3.8	4.0
17	P	38.5	4.1	38.7	2.3	4.0	6.5	3.8
	S	38.9	6.5	42.0	2.5	4.9	4.8	4.0
18	P	46.5	6.3	31.0	2.4	4.0	4.7	4.2
	S	29.7	4.5	24.6	1.7	2.9	3.3	2.6
19	P	33.3	3.8	19.6	2.0	8.7	7.6	3.4
	S	41.0	4.5	39.6	2.1	3.4	5.2	3.6
20	P	36.2	4.9	37.9	1.7	2.2	4.5	3.1
21	P	28.9	4.2	22.9	1.7	2.0	3.1	2.7
22	P	38.8	4.8	40.3	2.1	4.4	3.1	3.6
	S	40.0	5.3	38.4	2.0	3.1	4.1	3.6
23	P	38.1	6.2	48.5	2.5	4.9	4.9	3.7
	S	31.0	4.4	28.5	1.6	2.7	4.1	2.6
24	P	39.4	4.9	33.8	1.8	2.7	5.1	2.4
	S	23.7	3.5	20.7	1.6	1.6	5.6	2.3
25	P	38.9	6.3	38.9	2.2	2.4	7.1	3.8
	S	40.3	6.0	35.6	2.4	3.4	3.6	4.4
	S	44.8	6.9	39.9	3.5	3.4	8.4	3.4
26	P	41.3	5.5	37.5	2.1	2.4	3.8	3.5
	S	26.6	3.7	30.5	2.1	1.7	3.3	3.0
27	P	42.2	4.4	33.1	2.6	4.2	4.5	4.4
	S	45.5	5.9	43.1	2.4	5.2	4.3	4.5
28	P	37.5	5.6	46.5	2.3	3.7	4.6	4.4
	S	40.8	5.5	34.9	2.3	3.9	5.3	3.5
29	P	42.1	5.8	40.8	2.3	2.6	3.9	3.5
	S	44.6	6.3	33.6	2.9	2.3	5.2	4.4
30	P	29.2	3.9	22.9	1.7	2.3	3.2	2.2
	S	40.6	4.9	39.0	2.0	4.5	4.1	3.3
31	P	42.3	5.6	44.0	2.0	2.9	4.4	4.0
	S	40.9	5.7	41.6	2.3	3.4	3.5	3.5
Mean		36.7	4.9	34.3	2.1	3.4	4.6	3.4
SD		7.9	1.2	9.6	0.5	1.6	1.5	0.9
Min		23.1	2.4	14.9	1.5	1.5	2.8	2.2
Max		46.5	6.9	49.8	3.5	9.2	8.4	5.3

**Appendix 25.9: Retrospective Study. Herbage Composition (g kg<sup>-1</sup>) - November 1997**

Farm No	Crop	Se	Mn	Zn	Cu	Mo
5	P	0.16	118	40.0	10.1	3.3
	S	0.18	499	50.5	10.4	0.9
6	P	0.14	122	38.5	10.5	2.6
	P	0.10	146	42.1	12.4	3.0
	S	0.09	33	28.9	8.5	2.3
	S	0.08	133	30.6	10.2	1.0
7	P	0.06	108	33.9	10.6	1.9
	P	0.07	100	35.3	11.9	1.5
	S	0.09	93	26.8	8.0	4.3
9	P	0.24	44	38.9	10.7	2.1
	S	0.08	186	48.8	11.7	0.5
14	P	0.24	172	39.8	10.7	3.0
	S	0.08	476	42.5	8.5	3.0
15	P	0.17	367	35.0	9.7	1.9
	S	0.54	131	38.4	11.3	4.5
16	P	0.38	298	32.6	8.9	28.9
	S	0.24	150	37.5	11.2	36.3
17	P	0.08	66	35.3	10.1	3.8
	S	0.20	61	29.0	11.2	4.2
18	P	0.16	89	31.5	10.6	3.6
	S	0.18	636	36.9	7.8	1.6
19	P	0.08	95	26.0	6.8	2.9
	S	0.08	122	27.9	7.9	1.3
20	P	0.16	160	38.7	9.0	2.9
21	P	0.10	686	59.7	8.9	0.7
22	P	0.07	138	41.5	12.2	0.7
	S	0.08	110	48.7	16.4	2.7
23	P	0.10	60	32.1	8.5	8.9
	S	0.11	143	32.8	9.2	2.3
24	P	0.16	227	40.8	11.2	1.3
	S	0.18	436	40.4	7.2	2.4
25	P	0.07	57	34.3	4.7	13.0
	P	0.07	182	45.3	14.1	2.7
	S	0.14	139	32.4	10.0	7.3
26	P	0.06	203	36.5	10.1	7.9
	S	0.08	470	38.7	8.6	2.8
27	P	0.05	157	35.0	11.2	1.0
	S	0.06	152	36.0	11.2	0.6
28	P	0.08	70	41.6	11.9	3.8
	S	0.09	218	44.6	13.3	5.2
29	P	0.07	132	32.4	6.7	6.4
	S	0.06	117	34.5	10.2	1.5
30	P	0.12	282	35.5	6.2	1.0
	S	0.09	126	26.7	6.7	4.5
31	P	0.11	54	37.4	11.8	3.9
	S	0.08	161	38.6	10.9	2.6
Mean		0.13	186	36.4	9.8	4.3
SD		0.09	154	8.6	2.6	6.5
Min		0.05	33	26.0	4.7	0.5
Max		0.54	686	59.7	16.4	36.3

## APPENDIX 26

**Appendix 26.1:** Retrospective Study. Farm 13. Additional soil analyses (mg l<sup>-1</sup>)

Field		Extractable				
	pH	P	K	Cu	Zn	Mo
1	5.4	2.3	160	3.0	8.5	0.25
2	5.7	1.7	93	2.9	7.4	0.46
3	5.7	1.6	93	3.2	8.5	0.41
4	6.0	2.0	87	4.5	16.0	0.19
5	6.1	1.4	147	1.8	6.6	0.44
6	5.3	4.9	209	2.0	12.9	0.39

**Appendix 26.2:** Retrospective Study. Farm 13. Soil analyses. November 1997

Field	Total (mg kg <sup>-1</sup> )									
	Mn	Zn	Cu	Ni	Cr	Pb	Cd	Hg	Co	Se
1	905	108.5	11.4	25.5	20.6	49.6	0.50	0.08	9.1	0.45
2	1008	102.6	10.5	24.1	20.3	51.4	0.46	0.08	8.2	0.50
3	957	127.8	12.1	30.0	19.7	40.8	0.47	0.06	9.1	0.45
4	1322	157.4	16.5	31.5	19.2	44.7	0.76	0.07	9.7	0.49
5	1118	123.8	9.8	28.6	18.0	42.5	0.51	0.06	9.7	0.50
6	761	115.0	9.7	23.7	15.6	37.9	0.46	0.06	8.1	0.45

**Appendix 26.3:** Retrospective Study. Farm 13. Herbage analyses. November 1997

Field	g kg <sup>-1</sup>						mg kg <sup>-1</sup>			
	N	P	K	Mg	K	Ca	Se	Zn	Cu	Mn
1	20.4	2.7	24.7	1.8	1.3	3.2	0.05	34.6	8.1	459
2	19.6	2.0	17.2	1.5	0.8	3.5	0.06	30.6	8.8	308
3	17.5	2.0	16.6	1.4	0.8	2.8	0.05	40.0	6.8	462
4	20.0	2.2	20.7	1.6	0.7	3.6	0.04	30.1	6.0	234
5	18.7	2.1	18.7	1.9	1.5	3.0	0.07	23.6	6.8	463
6	23.5	3.2	26.2	1.9	2.3	3.7	0.05	27.4	6.8	576



## APPENDIX 27

**Appendix 27.1:** Spatial variation of selenium and other elements in soil and herbage from Farm 15, silage area

Plot No.	pH	Soil			Herbage Se (mg kg <sup>-1</sup> )
		Extractable (mg l <sup>-1</sup> )		Total Se (mg kg <sup>-1</sup> )	
		Cu	Zn		
1	5.9	27.2	9.2	22.0	2.6
2	5.6	44.5	14.7	22.5	2.3
3	5.3	39.6	14.3	18.0	1.2
4	5.5	23.0	14.3	21.0	1.4
5	5.4	22.3	8.0	14.0	3.9
6	5.5	21.3	10.8	15.5	5.4
7	5.5	15.5		14.5	2.8
8	5.5	20.6	12.4	13.5	2.0
Mean	5.5	26.8	10.5	17.6	2.7
SD	0.2	10.1	4.9	3.8	1.4

**Appendix 27.2:** Spatial variation of zinc and lead in soil (tilled) from Farm 24

Plot No.	pH	Extractable (mg l <sup>-1</sup> )		Total in soil (mg kg <sup>-1</sup> )		
		Cu	Zn	Se	Pb	Zn
1	5.4	3.6	14.2	0.6	93	241
2	5.5	3.6	68.0	0.5	216	533
3	5.5	2.9	17.2	0.6	95	236
4	5.4	3.0	38.3	0.7	146	313
5	5.4	4.3	41.5	0.6	174	347
6	5.4	4.3	34.5	0.6	126	248
7	5.5	4.8	28.3	0.6	180	319
8	5.8	9.8	364.0	0.7	1234	1596
9	5.5	5.1	103.0	0.5	275	445
10	6.4	9.4	365.0	0.5	151	772
11	5.5	2.5	17.0	0.4	128	221
Mean	5.6	4.8	99.2	0.6	256	479
SD	0.3	2.5	133.7	0.1	329	405

**Appendix 27.3:** Spatial variation of lead in soil (grazed area) from Farm 31

Plot No.	pH	Extractable (mg l <sup>-1</sup> )	Total (mg kg <sup>-1</sup> )		
		Zn	Se	Pb	Zn
1	6.4	11.8	0.9	1653	176
2	6.5	12.5	0.6	839	150
3	6.4	14.6	0.5	415	185
4	6.2	10.3	0.5	560	144
5	5.9	9.5	0.5	255	143
6	6.4	13.6	0.4	395	173
7	6.1	10.9	0.4	176	147
Mean	6.3	11.9	0.5	613	160
SD	0.2	1.8	0.2	507	18

## APPENDIX 28

### Appendix 28.1: Soils from Vole study locations

	Askeaton			Coole	
	0-200 m	200-400	ca 800+	Shanabhaile	Inch Wood
<b>pH</b>	7.7	7.8	6.8	7.7	6.9
<b>Extractable (mg l<sup>-1</sup>)</b>					
P	35	90	4.5	15	20
K	286	296	98	87	38
Mg	870	807	206	399	275
Mn	144	188	282	227	432
Mo	0.33	0.26	-	0.40	0.33
<b>Total (mg kg<sup>-1</sup>)</b>					
Cr	30.1	15.6	13.1	14.4	18.5
Ni	103.1	41.8	32.9	23.8	25.1
Cd	1.53	1.30	1.10	1.04	1.54
Cu	54.9	20.5	15.2	12.6	9.3
Zn	220.6	112.5	83.8	50.6	64.8
Pb	86.7	44.6	37.7	70.0	40.1
F	320	340	-	320	340
Se	0.40	0.40	0.75	0.50	0.40
Mn	619	593	1131	1201	619
Hg	-	-	0.07	-	-

<sup>1</sup>Distance from pier facing Aughinish Island. 0-200 m and 200-400 sites were on roadside verge : 800 m site was in adjoining fields

### Appendix 28.2: Comparative data for soils used in rat trial

Parameter	Test Soil (Askeaton)	Control Johnstown
<b>pH</b>	<b>6.7</b>	<b>5.9</b>
<b>Extractable (mg l<sup>-1</sup>)</b>		
P (mg l <sup>-1</sup> )	45	19
K (mg l <sup>-1</sup> )	360	210
Mg (mg l <sup>-1</sup> )	357	426
Cu (mg l <sup>-1</sup> )	6.3	2.8
Zn (mg l <sup>-1</sup> )	5.5	6.2

# An Ghníomhaireacht um Chaomhnú Comhshaoil

## Bunú

Achtaíodh an tAcht fán nGníomhaireacht um Chaomhnú Comhshaoil ar an 23ú lá d'Aibreán, 1992 agus faoin reachtaíocht seo bunaíodh an Ghníomhaireacht go hoifigiúil ar an 26ú lá d'Iúil, 1993.

## Cúraimí

Tá réimse leathan de dhualgaís reachtúla ar an nGníomhaireacht agus de chumhachtaí reachtúla aici faoin Acht. Tá na nithe seo a leanas san áireamh i bpríomhfhreagrachtaí na Gníomhaireachta:

- ceadúnú agus rialáil próiseas mór/ilchasta tionsclaíoch agus próiseas eile a d'fhéadfadh a bheith an-truailitheach, ar bhonn rialú comhtháite ar thruailliú (Integrated Pollution Control-IPC) agus cur chun feidhme na dteicneolaíochtaí is fearr atá ar fáil chun na críche sin,
- faireachán a dhéanamh ar cháilíocht comhshaoil, lena n-áirítear bunachair sonraí a chur ar bun a mbeidh rochtain ag an bpobal orthu, agus foilsíú tuarascálacha treimhsiúla ar staid an chomhshaoil,
- comhairle a chur ar údaráis phoiblí maidir le feidhmeanna comhshaoil agus cuidiú le húdaráis áitiúla a bhfeidhmeannas caomhnaithe a chomhlíonadh,
- cleachtais atá fónta ó thaobh an chomhshaoil de a chur chun cinn, mar shampla, trí úsáid iniúchtaí comhshaoil a spreagadh, cuspóirí cáilíochta comhshaoil a leagan síos agus cóid chleachtais a eisiúint maidir le nithe a théann i bhfeidhm ar an gcomhshaoil,
- taighde comhshaoil a chur chun cinn agus a chomhordú;
- gach gníomhaíocht thábhachtach diúscaitha agus aisghabhála dramhaíola, lena n-áirítear líontaí talún, a cheadúnú agus a rialáil agus plan náisiúnta bainistíochta um dhramhaíl ghuaiseach, a bheidh le cur i ngníomh ag comhlachtaí eile, a ullmhú agus a thabhairt cothrom le dáta go tréimhsiúil,
- córas a fheidhmiú a chuirfidh ar ár gcumas astúcháin COS (Comhdhúiligh Orgánacha Sho-ghalaithe) a rialú de bharr cáinníochtaí suntasacha peitiril a bheith á stóráil i dteirminéil,
- na rialúcháin OMG (Orgánaigh a Mionathraíodh go Géiniteach) a fheidhmiú agus a ghníomhú maidir le húseaid shrianta a leithéad seo d'orgánaigh agus iad a scaoileadh d'aon turas isteach sa timpeallacht,

- clár hidriméadach náisiúnta a ullmhú agus a chur i ngníomh chun faisnéis maidir le leibhéil, toirteanna agus sruthanna uisce in aibhneacha, i lochanna agus i screamhuiscí a bhailiú, a anailisiú agus a fhoilsiú, agus
- maoirseacht i gcoitinne a dhéanamh ar chomhlíonadh a bhfeidhmeanna reachtúla caomhnaithe comhshaoil ag údarás áitiúla

## Stádas

Is eagrais poiblí neamhspleách í an Ghníomhaireacht. Is í an Roinn Comhshaoil agus Rialtais Áitiúil an comirceoir rialtais atá aici. Cinntítear a neamhspleáchas trí na modhanna a úsáidtear chun an tArd-Stiúrthóir agus na Stiúrthóirí a roghnú, agus tríd an tsaoirse a dhearbhaíonn an reachtaíocht di gníomhú ar a conlán féin. Tá freagracht dhíreach faoin reachtaíocht aici as réimse leathan feidhmeannas agus cuireann sé seo taca breise lena neamhspleáchas. Faoin reachtaíocht, is coir é iarracht a dhéanamh dul i gcion go míchuí ar an nGníomhaireacht nó ar aon duine atá ag gníomhú thar a ceann.

## Eagrú

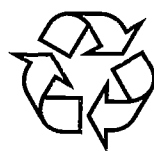
Tá ceanncheathrú na Gníomhaireachta lonnaithe i Loch Garman agus tá cúig fhoireann chigireachta aici, atá lonnaithe i mBaile Átha Cliath, Corcaigh, Cill Chainnigh, Caisleán an Bharraigh agus Muneachán.

## Bainistíocht

Riarann Bord Feidhmiúcháin lánaimseartha an Ghníomhaireacht. Tá Ard-Stiúrthóir agus ceathrar Stiúrthóirí ar an mBord. Ceapann an Rialtas an Bord Feidhmiúcháin de réir mionrialaigh atá leagtha síos san Acht.

## Coiste Comhairleach

Tugann Coiste Comhairleach ar a bhfuil dáréag ball cunaimh don Ghníomhaireacht. Ceapann an tAire Comhshaoil agus Rialtais Áitiúil na baili agus roghnaítear iad, den chuid is mó, ó dhaoine a ainmníonn eagraíochtaí a bhfuil suim acu i gcúrsaí comhshaoil nó forbartha. Tá réimse faisnéis feidhmeannas comhairleach ag an gCoiste faoin Acht, i leith na Gníomhaireachta agus i leith an Aire aiaon



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