Crop Conservation and Storage

In Cool Temperate Climates

Second Edition

Michael J. Nash

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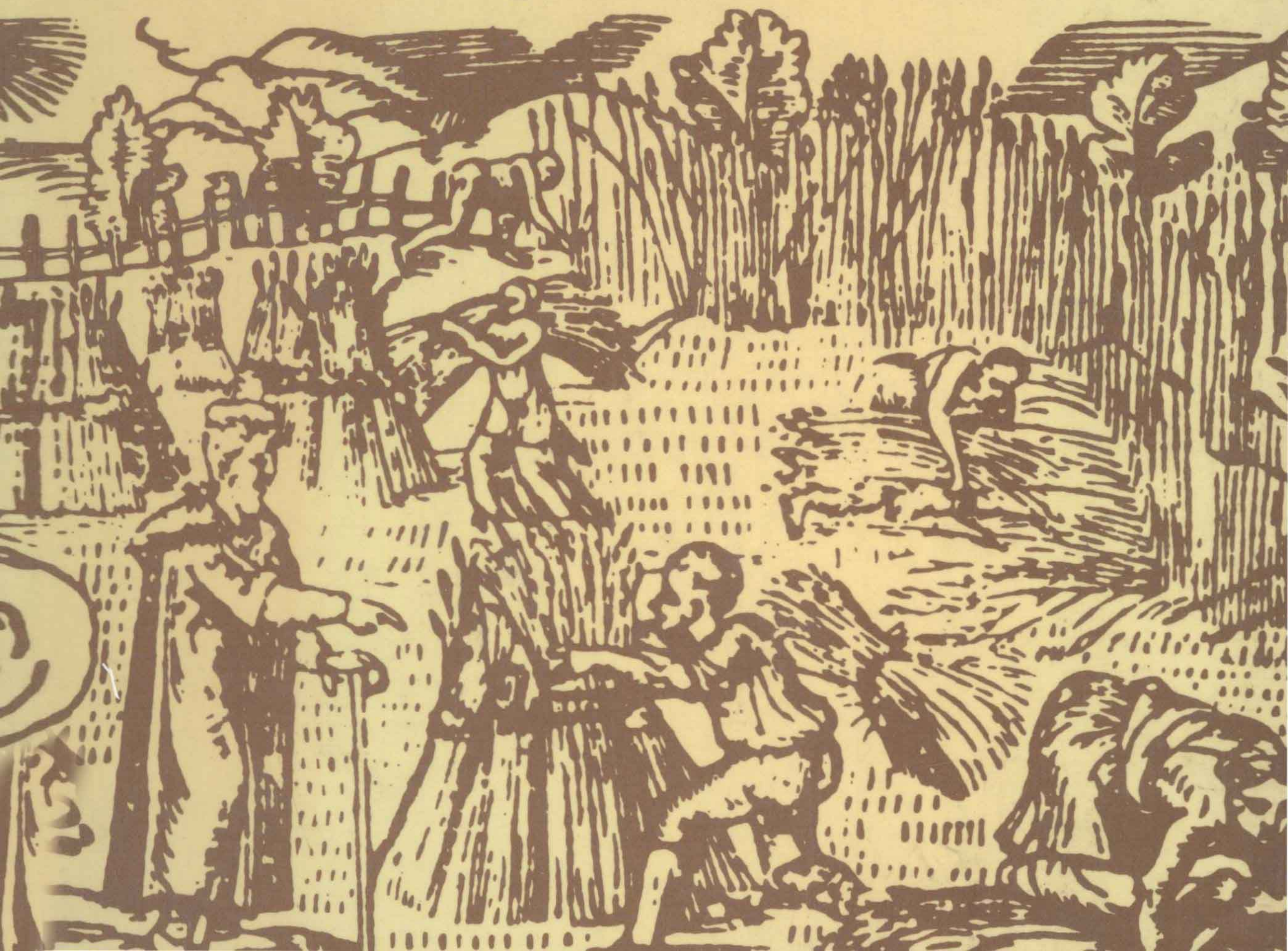

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IN COOL TEMPERATE CLIMATES

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SECOND EDITION

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CROP CONSERVATION AND STORAGE

IN COOL TEMPERATE CLIMATES

Dedicated to the memory
of
SIR STEPHEN WATSON

Professor of Agriculture and Rural Economy in the University of Edinburgh and Principal of the East of Scotland College of Agriculture from 1944 to 1968

". . . that our garners may be full,
affording all manner of store"

(Ps.144)

Preface to Second Edition

Since the First Edition was published in 1978 a further large number of papers have been read. Some of these report research into new techniques while others serve to further our knowledge on traditional techniques. A number of new books have also been consulted and some of these have been added to the list of "Selected books and reviews", at page 268. Taken altogether the literature published during the past few years has necessitated numerous changes, in particular to Chapters 1, 2, 7 and 8.

The chapter titles remain the same, with the notable exception of Chapter 7 which is now entitled "Supplementary treatments for conservation and storage" rather than "Pre-treatments for conservation and storage". Concerning the latter, it has been rightly pointed out that the use of the term "pre-treatments" implies that *all* treatments are applied before the crop is conserved or stored, whereas the text clearly shows that some are given either at the point of storage or even during storage. The use of the term "supplementary treatments" is also preferable for another reason; it emphasises the fact that treatments may be regarded as aids, not essentials, to the "primary" methods of conserving and storing crop produce. Accordingly, readers are asked to bear in mind that whereas the first five chapters describe the primary methods, these chapters pay little regard to techniques of aiding crop conservation and storage; the latter are dealt with as an entity in Chapter 7.

As regards chapter sections and sub-sections, it has been found appropriate to make some additions and alterations. Chapter 1 now contains a sub-section on the conservation of oilseed poppy. Likewise Chapter 2 contains new sub-sections on hay and silage made from big bales. This chapter also contains a new section entitled "The chemical preservation of partly-made hay", which should now be regarded as a primary conservation technique. The reason is that partly-dried hay will undergo rapid decay in the absence of complete chemical control. On the other hand, chemicals used merely as an "insurance policy" for hay already sufficiently dry for safe bulk storage, are covered in Chapter 7.

Lastly, on the matter of long-term storage of seed, it should be noted that during the past few years there has been increasing attention paid to arresting the decline in the world's plant genetic resources, by using specialised storage techniques. In this connection the reader's attention is drawn to the review article by M.W. King and E.H. Roberts, and to the book by J.R. Thomson (see "Selected books and reviews", p. 268).

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Acknowledgements to Second Edition

There are numerous people to whom I am grateful for assistance since the publication of the First Edition in 1978. I am again especially indebted to Mr A.K.M. Meiklejohn, a former colleague in the School of Agriculture, who has spent many hours editing and commenting on the entire manuscript for this Second Edition; no author could have hoped for more editorial skill and helpful advice and support than I have received.

Mr J.R. Thomson of the Edinburgh School of Agriculture has kindly updated his "A note on seed storage" as given in Appendix 1, as likewise has Dr. R.O. Sharples of the East Malling Research Station his "A note on fruit storage", Appendix 2. Professor T.A. Oxley, formerly Head of the Grain Storage Section of the Pest Infestation Laboratory, Slough, and now at the Biodeterioration Centre, University of Aston, Birmingham, provided valuable comment on the layout of the original text for which I am most grateful. Dr T. Watkins, Department of Archaeology, University of Edinburgh, and Dr D.C. Graham, Agricultural Scientific Services, Department of Agriculture and Fisheries for Scotland, have given further helpful comment. Dr D.E. Evans and other members of the Stored Grain Investigations Centre, Division of Entomology, C.S.I.R.O., Canberra, and likewise Mr P. Taylor and other members of the Division of Mechanical Engineering, C.S.I.R.O., Melbourne, provided information on physical and chemical methods of grain storage during my study leave to Australia in 1979, as did Dr J. Shejbal of the Association of ENI Companies for Scientific Research (ASSORENI) during a visit to Rome in 1980.

I must also thank a number of colleagues both in the University Department of Agriculture and in the East of Scotland College of Agriculture for information on their own recent researches. Last but not least I am most indebted to Miss E.C. Christy and Mrs A. Munro who took on the considerable task of copy-typing the updated manuscript.

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Preface to First Edition

Most people, on reflection, would probably agree that the conservation and storage of crops, both for humans and animals, is fundamental to civilisation as we know it. It is probably not widely appreciated, however, that knowledge on how to store crops developed before it was discovered how to cultivate crops.

The keeping of crops is just as crucial a matter today as it was in biblical times and earlier, and during the twentieth century much has been written on the subject. As yet, however, there has been no comprehensive agricultural text covering all crops, drawing together and concentrating the essential features of conservation and storage into one volume. This book, which aims to go some way towards filling this gap, is based on the experiences from experimentation and practice of hundreds of workers in Western Europe, including those of the author who, as agriculturalist on the Agricultural Research Council's Fodder Conservation Team and later as a member of the staff of Edinburgh University, was co-author of an earlier volume, *The Conservation of Grass and Forage Crops*, by Watson and Nash (1960).

We have reached critical times, and I hope that this work will arouse greater awareness of the importance of crop conservation and storage in man's constant effort to obtain his prime material need – a supply of good-quality food, both for himself and for his animals, without undue wastage. The book is directed at a wider readership than was the case with *The Conservation of Grass and Forage Crops.* It has not been easy to form a reasonable balance of subject matter to suit the needs of various groups of reader – student, lecturer, farmer, adviser, research worker – but, nevertheless for better or worse the following pages have been written for all concerned with this important area of agriculture.

The subject matter has been treated throughout from a biological viewpoint. Following the Prologue, which presents a background to modern storage methods, there are five chapters covering all the major crops as conserved and stored in cool climates: cereal grains, legume grains and the oilseeds; grass; green crops other than grass including the cereals, legumes and crucifers; potatoes; and the roots – sugar beet, fodder beet, mangels, swedes, turnips, red beet and carrots. The onion bulb, another important food, is considered along with the root crops. The approach to each of these crop chapters is essentially straightforward; a brief introduction, an outline of the scientific principles of conservation and storage, a discussion of the major problems involved, a description of methods, and an indication of the requirements for industrial processing. Little detail has been given on the nutritive value of the various crops although some numerical data are given in Appendix III.

Since a wide range of crops has been covered, certain matters have had to be excluded. Apart from generalised statements, the economics of conservation and storage systems have been left alone. These can only be meaningfully considered by the agricultural economist and farm management expert, and then only in the light of the economics of the whole farm. Nor has any attempt been made to discuss the multitude of operations involved in the growing of crops, for almost without exception the latter are aimed at achieving maximum economic yields and have little to do with the storage phase. A dividing line has thus been drawn between crop production and crop storage and, except for the chapter introductions, the theme of conservation and storage starts when the crop has reached, or nearly reached, the mature or ripe stage. Little consideration is given to the effects of the various conserved and stored products on animal performance, except where they have toxic or other undesirable effects. Apart from what has been said in the Prologue on fruit it has not been possible to write a special chapter on the storage of fruit, nor on seed storage, but these subjects are outlined in appendices written by Dr R.O. Sharples and Mr J.R. Thomson.

Chapter 6 is devoted to a consideration of crop by-products and miscellaneous foods, while Chapter 7 covers the benefits and limitations of pre-storage treatments. The important subject of the wastage and losses incurred in crop conservation and storage is dealt with as an entity in Chapter 8 rather than separately in the crop chapters. The Epilogue includes a statement on the requirements for successful conservation and storage, as may be practised in the near future by more and more farmers.

It is appropriate to explain the use of the terms "conservation" and "storage". The term conservation implies certain necessary and marked changes, whether physical, chemical or microbiological, which must take place either during the preparation of a crop for safekeeping, or during its storage. It is applied mostly to the major conservation products, hay, silage and artificially dried green crops. It does, however, also apply to other stored crops, including those which undergo no obvious changes. The term conservation may also be taken to mean preservation, i.e. the sudden arrest of biological changes, for example such as occurs when onions are immersed in vinegar, or when potatoes are canned. The term storage may refer to any crop, but it covers more specifically the physical requirements – buildings, equipment or any other resources necessary for the safekeeping of the produce.

Many hundreds of research publications from numerous countries, mainly in Western Europe, have been consulted. Space does not permit the inclusion of what would have amounted to a very lengthy bibliography, but a selected list of books and review papers is provided. With a few exceptions the American literature has had to be left untouched. However, although the book has been written around work done in the UK and neighbouring countries, the conclusions may be applied to any country or region which experiences a cool temperate climate – whether maritime or continental.

Finally, although I have written a special and separate list of Acknowledgements, I must pay tribute to many not specifically mentioned, who through their researches have helped to make this work possible.

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Acknowledgements to First Edition

I am greatly indebted to Mr J.R. Thomson of the Edinburgh School of Agriculture for so readily agreeing to write "A note on seed storage", as given in Appendix 1, and likewise to Dr R.O. Sharples of the East Malling Research Station for producing "A note on fruit storage", as Appendix 2. Also, I am most grateful to Dr R.C.F. Macer, Director of the Scottish Plant Breeding Station, formerly Professor of Crop Production in the University of Edinburgh, for having undertaken to read and comment on the text, chapter by chapter, as each was written. To Mr A.K.M. Meiklejohn, a former colleague in the School of Agriculture, I cannot adequately express my appreciation for the many hours he spent editing and commenting on the entire manuscript. His unstinting help and advice were given in his characteristically generous and friendly manner.

Many have assisted in various ways; by reading parts of chapters, or whole chapters, by sending me reprints of their published work, allowing me access to unpublished work, or giving me specific advice. In particular I wish to thank Professor K.D. White, formerly of Reading University, now of the Department of Humanities, University of Jos, Nigeria; Dr G.E. Rickman, Department of Ancient History, University of St. Andrews; Professor S. Piggott and Dr T. Watkins, Department of Archaeology, University of Edinburgh; Mr N.J. Burrell and Mr S.W. Pixton, Pest Infestation Control Laboratory, Ministry of Agriculture, Fisheries and Food; Dr A.D. Drysdale, BP Nutrition (UK) Limited; Mr M. Bearman, Quenby Price Limited; Mr J. Wright, Home-Grown Cereals Authority, London; Mr G.W.H. Insill, Scottish and Newcastle Breweries Limited; Professor J.C. Murdoch, Agricultural Research Institute, Northern Ireland; Mr W.F. Raymond, Ministry of Agriculture, Fisheries and Food, London; Dr R.J. Wilkins, Mr R.M. Tetlow and Dr M.K. Woolford, and Dr J.M. Wilkinson, The Grassland Research Institute; Professor R. Whittenbury, Department of Biological Sciences, University of Warwick; Dr N.W. Pirie, Dr G.F.J. Milford and Dr J. Lacey, Rothamsted Experimental Station; Dr A.S. Jones and Dr J.F.D. Greenhalgh, The Rowett Research Institute; Dr M.E. Castle, The Hannah Research Institute; Professor J.K.A. Bleasdale and Dr W.G. Tucker, National Vegetable Research Station; Mr G. Shepperson, Mr H.J.M. Messer and Mr R.H. Charlick, National Institute of Agricultural Engineering, Bedford, and Mr R.G. Clark, Scottish Institute of Agricultural Engineering; Dr D.A. Bond, Dr E.S. Bunting, Dr K.F. Thompson and Mr S.J. Brown, Plant Breeding Institute, Cambridge; Dr I.H. McNaughton, Scottish Plant Breeding Station; Dr W.G. Burton, Food Research Institute; Dr J.S. Woodman, formerly of the Campden Food Preservation Research Association; Dr D.C. Graham, Agricultural Scientific Services, Department of Agriculture and Fisheries for Scotland; Mr J. Crawford, Golden Wonder Ltd.; Mr J.F.T. Oldfield, Mr J.V. Dutton and Mr M. Shore, British Sugar Corporation Ltd.; Dr R. Hull and Dr W.J. Byford, Broom's Barn Experimental Station; Mr M. Selman, Gleadthorpe Experimental Husbandry Farm; Mr A.L. Francis, Bridget's Experimental Husbandry Farm; Professor W. Ellison, University College of Wales; Professor J.D. Ivins, University of Nottingham; Professor I.A.M. Lucas and Dr G.M. Davies, University College of North Wales.

Likewise I am grateful for similar help received from many of my colleagues at the Edinburgh School of Agriculture, both in the University Department of Agriculture and in the East of Scotland College of Agriculture. Dr B.D. Witney kindly offered guidance on conversion factors, and Dr A.D. Trapp produced Figs. 1.6, 2.1, 2.2, 2.4, 4.1 and 4.2. Mr G. Finnie of the Photographic Unit carried out the art work for the graphs and Mr J.J. Dunn prepared photocopies. Miss J.K.H. Playfair, the Librarian, and her staff assisted in various ways, including the location of valuable reference material. Most especially, I must thank Miss L. Mocogni and her staff for many hours of audio-typing and copy-typing. Their work was carried out with patience and kindly interest over many months, and without one word of complaint.

There are a number of other bodies to whom I owe a special word of thanks — The Society of Antiquities of Scotland, The Society of Antiquaries, London, and Collins Publishers, London, for allowing me to reproduce Figs. 1, 2 and 3 of the Prologue, and the Institute of Archaeology, University of London, for permitting me to use material given in Table 2 of the Prologue. The data for nutritive value of crops for conservation, presented in Appendix 3, have been extracted, and rearranged, from MAFF Bulletin No. 33, published in 1975 by Her Majesty's Stationery Office. I am grateful to Dr P.M. Smith of the Department of Botany, University of

Edinburgh, for checking all Latin names of crop plants, and to Aberdeen University for allowing me to quote from a PhD thesis by A.O. Olorunda, "Storage and post-harvest physiology of root crops" (1973).

The writing of this book was greatly expedited by my release from a number of University duties, for which I am indebted to Professor N.F. Robertson, Professor of Agriculture and Rural Economy in the University of Edinburgh and Principal of the East of Scotland College of Agriculture.

Finally, I owe a debt of gratitude to my family for many enforced sacrifices, and to my son, Stephen, who offered a number of helpful comments.

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Contents

Prologue

A Background to Present-Day Conservation and Storage

"No-one stores up produce save with the intention of bringing it out again". (Varro, 36 BC)

Introduction

The majority of present-day crop storage methods were known and used thousands of years ago. Some of the evidence is fragmentary, but there is sufficient to indicate that the well-known storage techniques of drying (both natural and artificial), sealing (airtight storage), cooling, freezing, fermentation, pickling, salting and smoking were all used, albeit often in a crude way, a very long time ago. With certain exceptions such as canning, a modern offshoot of airtight storage, today's storage methods are developments of principles which have been worked out by trial and error over many centuries.

Thanks to the scientific advances of the twentieth century it has become possible to comprehend exactly why, how and under what conditions these principles operate. Unfortunately, the practical application of these principles still lags behind the advances of science. Every year many mistakes are made in commercial practice: harvesting and storage losses are frequently high, while the quality and nutritive value of the stored products are often low. Good management, both at harvest and in store, is undoubtedly the key to success, despite the fact that storage problems often arise as a result of wet weather conditions occurring at the most critical time of all, namely, harvest. Crops which are stored in cool temperature climates are not plagued by rodents and insects to the same extent as those of the warmer parts of the world. But fungal and bacterial diseases together with the associated overheating, moulding and rotting of the stored products account for losses much greater than many realise.

SECTION 1: CIVILISATION AND STORAGE

The development of conservation and storage

Many will agree that it is knowledge on how to store food, as distinct from how to obtain a supply of food, which is responsible for the development of civilisation as we know it. Indeed, it is hardly an exaggeration to say that civilisation is based on crop storage. Coles (1973) in his book *Archaeology by Experiment* goes further by saying,

> "The status of a human group, the organisation of its economy, the size of population, all depend to a certain extent on its success in planned food utilisation, and in this, storage is of paramount importance."

Unfortunately, compared to the wealth of information on how crops were grown and cultivated thousands of years ago, that on how they were stored is limited. The range of crop material was undoubtedly large, just as it is today. The plants were, of course, growing in a wild state, but many were destined to be developed into more productive forms, and some to find their way to countries where there were more suitable environments for growth. Indeed, it is widely agreed that almost all the so-called cool temperate crops now grown in Western Europe originated from much warmer climates, and that a large number of them have come from the Near and Middle East, and from the Mediterranean area.

The ancient Palaeolithic or Old Stone Age provides no evidence of crop cultivation, and certainly no trace of crop storage (Table 1). The succeeding Mesolithic period provides some indication of cereal crop usage as, for example, the milling stones, pestles and mortars discovered during the well-known Mount Carmel explorations of the 1930s, while there is now

TABLE 1. Food storage: The basis of civilisation
(after Nash, *J. Roy. agric. Soc. Engl.*, 1980, **141**, 44–56)

Period	Approximate dates (mid-East)	Development of food storage
PALAEOLITHIC	ending *ca* 10 000 BC	Hunting, gathering. No evidence of food storage
MESOLITHIC	*ca* 10 000 → 7000 BC	Gathering and storage in some areas. Beginnings of settlement
NEOLITHIC	*ca* 7000 → 3000 BC	Establishment of farming life, with both crop storage and crop cultivation
– New Stone	*ca* 7000 → 5500	
– Copper	*ca* 5500 → 3000	
BRONZE	*ca* 3000 → 1100 BC	Adoption of technological innovations
IRON	*ca* 1100 BC onwards	
ROMAN	*ca* 100 BC → 400 AD	Storage techniques by now becoming more developed

TABLE 2. Early methods of conservation and storage
(after Nash, *J. Roy. agric. Soc. Engl.*, 1980, **141**, 44–56)

Method	Major foods
Airtight sealing	Grains, seeds, hard fruits
Drying	
– ambient air, – heated air	Grains, seeds, fruits, meat, fish, cereal/legume/grass fodders, tubers
– freeze air/defreezing	Potatoes ("chuno")
Cooling	Hard fruits, roots, tubers
Freezing	"Polar" foods
Fermenting	Wine, fodder (hay ↔ silage)
Smoking	Fish, meat
Salting	Fish, meat
Pickling	Vegetables, fruit

evidence from sites of this period, in Israel and Syria, of storage pits which were used for keeping harvested wild grain. So far as we know at present, therefore, crop storage in that area began in Mesolithic times, i.e. around 8000 BC, by radio-carbon dating, and the point of interest is that the storage of grains and seeds preceded rather than followed the practice of cultivating cereal crops; it was the wild grain that was stored.

The story of crop conservation and storage becomes increasingly fascinating as one moves from the New Stone Age and Copper Age into the Bronze Age, and thence into the Iron and Roman Ages. It has been said that the Romans were far ahead of their time, and that their technology was not to be equalled in Europe until the Renaissance. This may well be true, although, as will be seen later, some of their advanced ideas on storage were probably based on methods practised around 2000 BC, or earlier. It is unnecessary to bring the reader historically any nearer to our own times than the Roman Age, since by the time Roman civilisation had reached its zenith almost all of our present-day techniques had been discovered. In addition to canning the exceptions are vacuum drying, modern chemical preservation and 'hypobaric' or low-pressure storage.

The early methods of conservation and storage are outlined in Table 2. The particular method chosen depended on the kind of food and its perishability and, to some extent, on which part of the world was involved.

The significance of settlement

In very early times knowledge on how to store food was minimal. However, man's ancient practice of hunting herds of wild animals grazing on areas of land containing wild grasses and other plants, along with that of collecting various foods including the grain of those same wild plants as were grazed by his animals, were to be the prelude to a change of life style in the Near and Middle East – the development of the settled community. A settled community depended upon the ability to store food and, as already indicated, *knowledge on how to store crops probably developed before it was discovered how to cultivate and grow crops.*

It is widely agreed that the discoveries of how both to grow and store crops allowed man to change his way of life from that of a nomad to that of a settler. This change towards stable food supplies and a settled life was to affect all future generations. It is often said that, unlike the nomadic community, the settled community allowed time for the development of culture as distinct from agriculture, i.e. the development of activities other than those solely concerned with producing food. We now know from anthropologists' reports, however, that nomadic hunter-gatherers of today may have plenty of leisure-time. For example, investigations into the cultural habits of the food-gathering bushmen of Botswana reveal that such tribes have considerable spare time, and that they could easily become truly settled if they so wished. The investigations quite overturn the classical view that food gatherers are unable to become settled because they are so busily occupied securing adequate food and are constantly struggling to survive. It now seems clear that it is not leisure *per se* but food storage which has permitted true settlement, and hence the development of civilisation.

The time-lag from East to West

Although it is probable that certain agricultural techniques such as crop storage were learned indigenously in different parts of the world at different times, it is a reasonable generalisation to say there has been a gradual transference of knowledge mostly in one direction, namely from East to West. Also, from the available evidence, it would seem that crop storage and crop cultivation arrived together in Western Europe, not separately.

The time taken for the spread of knowledge on agricultural practices and their adoption in Western Europe was considerable. However, it will be noticed from Table 3 that the "time-lag" becomes less as the ages pass, taking at least 3000 years in the case of the Neolithic Age, but only 1200 years or thereabouts in the case of the Bronze Age. The Iron Age cultures spread even more rapidly in comparison with the earlier ages, requiring only 400 years.

There are two major reasons for this increasing rapidity of transference of knowledge. First, compared to the spread of the Neolithic cultures, which involved a complete change in the way of life, from one largely comprising hunting and gathering of food as occurred in the Mesolithic period to that of settled village farming in the Neolithic period, the spread of the Bronze and Iron Age cultures involved only the adoption of technological innovations, which did not cause a basic change to the agricultural way of life. Second, populations were increasing during each Age, so as time went by new ideas were being transmitted from East to West at an increasingly rapid rate from one concentration of population to another. In Europe the earliest evidence of agriculture occurs in Greece, where a few early Neolithic sites indicate the storage of wheat, barley and lentils.

TABLE 3. Spread of knowledge from East to West (dates given are approximate starting dates, all BC)

Culture	Development in Near East	Development in W. Europe
Neolithic (New Stone, Copper)	7000	4000*
Bronze	3000	1800
Iron	1100†	700†

* 4000 BC for the Netherlands, 3500 BC for N. France and Britain.

† These dates are based on conventional, historical dating, because at the present time discrepancies exist between historical and radio-carbon dating. The conventional method is preferable in these two instances until a radio-carbon correction system has been agreed upon.

Two examples of crop transference may be of interest. The first concerns lucerne (*Medicago sativa* L.). Klinkowski (1973) has traced the migration of this, the world's most important forage plant, named alfalfa ("the best fodder plant") by the Moors, over a period of 2500 years – from the south-east Caucasus – Caspian Sea area to Europe, South America, North America and many other parts of the world. Lucerne reached England in 1630. The other is beans (*Vicia* spp.) which, on account of their relatively high content of protein, formed an important part of the diet of the ancients. The island of Crete which certainly had agricultural trade with Egypt is noted for its agricultural development during the thousand years, 2800 to 1800 BC (historical dating), which archaeologists call the Early Minoan Period. It was during the famous archaeological investigations of the twentieth century AD that workers came across beans in the ancient storerooms of the city of Knossos. The beans were instantly recognised as identical to those being imported from Egypt.