STORAGE OF ORGANICALLY PRODUCED CROPS

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EXECUTIVE SUMMARY

The main objective of this review was to establish best storage practice for field vegetables, potatoes, cereals and top fruit. A literature review was carried out and information was also gathered from the industry. Information relevant to growers and farmers has been drawn together to provide a comprehensive base from which technical advisory leaflets can be produced. The costs of different storage methods are provided, and case studies used wherever possible.

In general, organic crops can be stored using the same methods as conventional crops but there is an increased risk that sometimes there will be higher storage losses because pesticides and sprout suppressants are not used. On the whole, specific problems with pests and diseases can be avoided using good organic husbandry techniques and by storing undamaged, healthy crops. In the case of cereals storage at correct moisture content and temperatures can avoid pests and moulds. However, there are some areas where more technical development or research would be useful and these have been identified.

Relatively few organic growers store vegetables, but in order to maintain a supply of good quality UK produce throughout the year, more long term cold storage space is required (either on farm or in co-operative type stores). Based on the limited data available, economic analysis revealed that long term storage of organic vegetables has generally not been profitable. However, as the market expands in the future, it is likely that storage will become as essential for vegetables as it is for organic cereals and fruit.

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ABBREVIATIONS

ABC	The Agricultural Budgeting and Costing Book
ADAS	Agricultural Development and Advisory Service
BOF/OGA	British Organic Farmers/Organic Growers Association
DANI	Department of Agriculture Northern Ireland
DTI	Department of Trade and Industry
EC	European Community
EFRC	Elm Farm Research Centre
EU	European Union
HDRA	The Henry Doubleday Research Association
HGCA	Home Grown Cereals Authority
HRI-W	Horticulture Research International, Wellesbourne
IFOAM	International Federation of Organic Agricultural Movements
MAFF	Ministry of Agriculture Fisheries and Food
NIAB	National Institute of Agricultural Botany
OMC	Organic Marketing Company
pers. comm.	Personal communication
PMB	Potato Marketing Board
RASE	Royal Agricultural Society of England
RH	Relative Humidity
SAC	Scottish Agricultural College
SCOAEFD	Scottish Office Agriculture, Environment and Fisheries Department
UK	United Kingdom
UKROFS	United Kingdom Register of Organic Food Standards
WOAD	Welsh Office Agriculture Department

1. GENERAL INTRODUCTION

1.1 PURPOSE OF REVIEW

At present there is a large demand for out of season organic produce in the UK but the majority of this is met by imports. As a measure to encourage more storage of organic produce and stave off increasing imports, Ministry of Agriculture Fisheries and Food (MAFF) commissioned this report to establish best storage practice for organic field vegetables, potatoes, cereals and fruit. More and better storage should reduce wastage, increase quality to the consumer and enable individual producers to increase their production and in turn enable them to supply more of the domestic demand. It is also envisaged that as the number of organic producers increases and as the volume of produce increases there is likely to be a greater necessity and incentive to store. The relatively new development of direct marketing of organic vegetables e.g. box schemes, has also created an interest and need for field vegetable storage where growers wish to supply their customers all year round and improve the quality of produce reaching their consumers.

1.2 AIMS OF REVIEW

In order that the consumer can receive good quality produce it is important that storage is carried out correctly through the whole of the supply chain from grower/farmer, to wholesaler/miller and retail outlet. (In the case of direct marketing the chain is much shorter and often only involves the grower and consumer.) The success of operations further down the chain rely on how the produce has been treated beforehand. The remit of this project is to concentrate on growing practices and storage methods which can be carried out by the organic farmer/grower. The crops reviewed by the project are field vegetables, potatoes, cereals and top fruit.

The main aims of the review are to:

1) Provide and disseminate information for advisors and farmers on best storage practice for organic crops.

2) Provide and disseminate information for advisors and farmers on good organic growing practice which improves the likelihood of successful storage.

3) Evaluate current conventional storage technology and establish whether it complies with organic standards, UKROFS (United Kingdom Register of Organic Food Standards).

4) To assess existing storage methods and practice to determine which methods are most appropriate for organic produce, the size of organic holding, the finances available, and the type of market supplied.

5) Using the limited information available on organic prices, consider the economics of storage and establish whether direct financial gains can be achieved.

6) To provide estimates of the costs of different storage methods and buildings, using case studies where possible.

7) To evaluate the suitability of new developments in storage research and technology for their use in organic systems. Any which potentially comply with organic philosophy will be brought to the attention of UKROFS to be considered for permitted use.

8) To try and envisage where problems and questions may arise if more farmers convert to organic production and more organic produce is stored.

9) To establish areas where more research or technology development would be useful.

1.3 APPROACHES

1.3.1 Consultation with farmers and the industry

In order to choose appropriate storage technology it was vital to find out what crops farmers and growers envisaged they would store, quantities they were likely to store, what problems they have when they try to store, what sort of information they require, and in the case of vegetable growers the reasons why they don’t store at present. In the initial stages of the project this involved consultation with the organic industry. Some organic growers and others in the industry who already store successfully have useful experience and knowledge which has contributed to the review. A list of the main individuals and organisations who contributed is given in the acknowledgements.

1.3.2 Literature review and consultation with researchers

The second approach was to carry out a literature review of scientific journals, HDC reports, and the grower and farmer press. Electronic databases such as Current Contents and Knowledge Index were scanned, these cover publications dating from 1972. Much of the information on field and clamp storage dates back further than this, hence, traditional library searches were carried out at The Henry Doubleday Research Association (HDRA), Horticulture Research International - Wellesbourne (HRI-W) and Writtle Agricultural College. The Potato Marketing Board (PMB) were also very helpful providing back issues as well as their more recent reports. This provided information on storage technology used for conventional produce and relatively recent research and technology developments which could either be directly used for organic produce or adapted. For current and future information on research and technology development, researchers, companies selling storage equipment and conventional growers were also contacted.

1.4 TECHNOLOGY TRANSFER AND DISSEMINATION

1.4.1 Vegetable storage workshop - November 19th 1996

An immediate need for information on vegetable storage for growers was identified at the beginning of this review study. In response a storage workshop was organised by HDRA and the Soil Association in conjunction with a National Institute of Agricultural Botany (NIAB) variety trials open day. Guest speakers were:

Peter Rickard	A storage consultant, who gave an overview of vegetable storage techniques ranging from field storage to the latest technology available.
Hugh Chapman	An organic vegetable grower with 6 acres who runs his own box scheme using storage methods appropriate to the size of his holding, including field storage, clamp storage and simple storage methods in a barn.
Guy Watson	An organic vegetable grower with 161 acres supplying a box scheme and the supermarket trade who has a small transient cool store and a separate cool store for long term storage.

The workshop was very well attended (90-100 people, 40-50 of which were growers). It was a useful day for exchange of information and for assessing the storage problems faced by existing organic growers.

Notes on the talks were taken and distributed to growers who requested them especially those who were unable to attend the day.

1.4.2 Presentations

A paper ‘Storage of Organically produced crops’ was presented at 10th National Conference on Organic Food Production at the Royal Agricultural College, Cirencester, 3rd - 5th of January 1997.

It is intended that a further presentation will be made at an Organic Food Production Conference or similar.

1.4.3 Information for EFRC and other advisors

The full report for this review project will be made available to MAFF, Elm Farm Research Centre (EFRC), British Organic Farmers/Organic Growers Association (BOF/OGA), Soil Association, UKROFS, and the Agricultural Development Advisory Service (ADAS).

1.4.4 Papers and articles in the press

Bevan, J. (1997) 'Storage - extending availability' New Farmer & Grower, 54, Summer 1997. This was a short article prepared for the organic farming press providing information on the physiology of storage and relating this to transient and long term cool storage.

Long, E. (1996) 'Gearing up to store' which appeared in Farmers Weekly on 16th of December 1996 (Report on storage workshop).

It is intended that more articles for the farming press will be produced to distribute advice on the storage of specific crops and the storage of different crops together.

1.4.5 BOF/OGA leaflets

Relevant parts of the review will be used to produce at least one grower/farmer guide on best storage practice. This will be in collaboration with the Soil Association who are producing a series of guides (31 in total) - 'Soil Association's Technical Guides for Organic Food Production'. The Soil Association is committed to produce the guides as part of a Sector Challenge grant funded by the Department of Trade and Industry (DTI) and trade sponsorship. After publication the guides will be made widely available within the industry.

2. STORAGE OF ORGANIC FIELD VEGETABLES AND POTATOES

2.1 SUMMARY

Relatively few organic growers store field vegetables. This is generally due to the small size of holdings, the wide variety of crops grown on each farm, and the under supply of the market leading to high prices at time of harvest. There are few incentives, in terms of price increases over the storage season to make storage worthwhile purely for profit or to justify the extra cost of storage buildings. In the next few years as the supply of organic vegetables increases there is likely to more necessity to store. Growers who direct market and wish to supply their customers all year round also need some form of storage.

Despite reservations at the beginning of this study that storage of organic vegetables would pose serious problems in terms of losses during storage i.e. postharvest diseases and sprouting, the same storage methods used for conventional crops can be used for organic crops. However, it has to be accepted that there may be a higher risk of problems developing in store and that some of the time there will be larger quantities of grade-outs.

Essentially the costs of organic storage are similar to those of conventional vegetable storage but the quantity of grade-outs can determine whether a profit or a loss is made. Unfortunately, the quantity of grade-outs is very unpredictable, making estimates of financial impact difficult.

There are a number of existing organic management practices which can help avoid storage losses. These start with the growing and management of the crop. Crop rotations, avoidance of nutrient over supply, use of disease free seed, suitable varieties and strategies to avoid pests and diseases which infect or contaminate before harvest are all important. The greatest emphasis has to be placed on correct timing of harvest, harvesting in dry weather, and the careful handling of crops during harvest and grading to avoid damaging the crop. Even for the storage of conventional crops it is recognised that postharvest handling has a greater influence on the outcome of storage than the use of postharvest pesticides. The appropriate management strategies along with appropriate storage techniques are drawn together in this review.

Appropriate storage methods

There are a number of different markets that organic growers supply, these have to be taken into consideration when deciding on a storage method. It is possible to draw some general conclusions which provide useful guidance, but it will always be necessary for a grower to assess and cost their own storage situation. There are a wide range of storage systems. If the

best alternatives are chosen, storage could be made more profitable. Improvements in production and marketing could also have a great effect on the profitability of storage. For example, the establishment of a good box scheme or links with retailers, could make it feasible to invest in better storage.

Organic growers who direct market their produce often have the disadvantage that they need to store relatively small quantities of a wide range of produce. Deciding which storage method to adopt can be difficult. On the other hand direct marketing has many advantages, growers know they can sell their produce and know how much they need to store. Cosmetic quality is not so important and the produce can be sold unwashed. This makes low technology options feasible for a wider range of crops than would be acceptable for the supermarket or wholesale trade.

Field storage is suitable for parsnips, swedes, carrots and savoy cabbage until March. For parsnips and carrots this provides the best storage method to preserve skin finish for the supermarket trade, where the carrots are sold washed. Field storage is not always appropriate, organic growers are often on unsuitable heavy land, and bad weather can make lifting impossible. Carrots usually need insulating with straw, the large quantities used make it costly and difficult to dispose of.

Clamps (indoor and outdoor) and adapted buildings using ambient convective ventilation are all suitable for short (until December) to medium (until March) term storage. All involve low fixed capital investment and so allow flexibility in decisions on whether to store or to sell off the field. They result in low annual running costs per tonne(£2-12/tonne) and are thus suitable for use with crops such as onions, swedes and beetroot for the wholesale and supermarket trade. Potatoes will only store in clamps without sprouting until January/February. Storage beyond this point would only be satisfactory for the direct marketing of small quantities where it is feasible to remove the sprouts prior to marketing. Presently, price increases over the winter season will adequately cover the cost of these forms of storage. Carrots and cabbage can also be stored this way for direct marketing outlets.

Ambient air cooled stores which are highly insulated and have fan assisted ventilation can provide relatively cheap (£25/tonne) and more reliable storage, especially for larger tonnages. However, greater price premiums must be achieved to give a satisfactory return on the amount of capital invested.

Refrigerated storage involves increased costs. There are clear economic advantages to using transient cold storage, to remove field heat and to keep produce in good condition. The use of a refrigerated container offers a reasonably low-cost place for an individual grower to begin.

Long term cold storage (costing £30-40/tonne) requires that a premium is obtained from selling produce in April and May to make it profitable. Economies of scale exist for larger stores which, in the case of many small producers, point the way towards co-operative ventures in storage. The present wide distribution of organic growers could make this difficult at present.

Box storage, although it requires higher initial investment, is more suitable than bulk storage. It is the most practical way to keep different crops separate within the same store and any storage rots are likely to be kept localised within particular boxes. Boxes can be removed from the store as required and damage during handling can be minimised.

Mixed storage. Organic growers tend to produce small quantities of a wide range of crops and find that they need to keep different crops in the same store. There is relatively little published information on long term storage of different crops together. Most information is for transient storage of relatively perishable crops. However, mixed storage is possible and organic growers practice it with success for crops such as potatoes, carrots, onions and cabbage in refrigerated storage. It is also possible with the simpler forms of storage.

Controlled atmosphere storage. In the future this developing technology will be useful for prolonged storage of several vegetable crops. Its use is already permitted in EU and IFOAM standards. The position over the permitted use of this technology needs to be considered and clarified by UKROFS and other UK approved organic sector bodies.

Useful areas of research specific to organic vegetables include:

- Development of clamping techniques using bulk boxes in a trench and straw bales to cut down on labour costs (carrots mainly)
- Storage in pits of root crops in bulk bags and boxes.
- Incorporation of straw and its effects on following crops.
- Varieties suitable for storage - information on varieties which are resistant to storage/diseases (all crops) - and varieties which store well when grown and stored organically without sprout suppressants.
- Ways of dividing up a cool store to provide optimum conditions for different crops within the same store e.g. polythene wrapping, insulated tents.
- Non chemical defoliation methods for potatoes.
- Research on storage life of different crops stored together at sub-optimum temperatures e.g. at 4ºC.
- Comparison of storage life of onion sets versus direct drilled or module raised onions.
- Collection of more information on organic market for economic analysis.

Other areas of research that are being covered to a certain extent by conventional research but could have implications for organic vegetable storage are:

- Rapid disease diagnostic tests to detect seed borne diseases. When the use of organically raised seed becomes mandatory it will be important that seed can be shown to be disease free.
- Rapid disease diagnostic tests to establish whether a crop has good storage potential.
- Varieties of potato less prone to low temperature sweetening.
- Detecting levels of soil borne diseases - many are responsible for postharvest rots.
- Forecasting to predict storage life of crop (some modification for organic produce may be required).
- Biological control.
- Controlled atmosphere storage to prevent sprouting and diseases. Some research specific to organic crops may be required.

2.2 IDENTIFYING THE ADVANTAGES, DISADVANTAGES AND PROBLEMS OF STORING ORGANIC VEGETABLES

2.21 Introduction

The remit of this project was to concentrate on crops which can be stored for a relatively long time. This includes onions, carrots, parsnips, swedes, beetroot, cabbage and pumpkin. The storage of potatoes is also included in this section because organic growers tend to grow a wide range of vegetables including potatoes, and the storage methods which can be used are similar. Section 2.3 describes each type of storage method and the situations where they may be appropriate. Section 2.4 deals with matters related to specific crops e.g. cultural methods which promote storage success and storage methods which lend themselves to these specific crops.

2.2.2 Reasons why organic vegetable growers do not store

At present very few organic growers store their produce and have not invested in buildings or equipment specifically for storage. There are several reasons:

A lack of incentive. Most growers supplying the wholesale and supermarket trade are able to sell all of their produce as soon as it is harvested. The UK demand for organic fresh vegetables and fruit far outstrips domestic supply. During 1996 UK production only supplied 25% of the total UK market (Organic Marketing Company (OMC) Ltd and Soyfoods Ltd, 1997, pers. comm.). The remainder had to be made up with imports. For most vegetables the market is not over supplied at any one time and consequently there is no great incentive for individual growers to store. Much of the demand is for out of season produce, but so few organic vegetable growers store at present that this demand has to be met almost solely by imports.

Economies of scale. Vegetables are grown on a variety of holdings, firstly, small horticultural/market garden scale, secondly on larger field scale specialist vegetable farms and lastly on arable farms which have field scale vegetables in their rotation. Organic producers tend to be on small holdings. In a recent analysis of UKROFS registered organic holdings in England and Wales in 1996 (Lampkin, 1997, pers. comm.), one third of organic holdings were classified as less than 8 European Business Units (EBU's), effectively part-time, and a further one third came into the 'small' farms category of 8-40 EBUs. The tendency to small business size is particularly marked for horticultural producers. As a consequence the quantity of crop for potential storage from a particular holding tends to be small. This, coupled with the relatively low incomes generated by these types of holdings, has meant that growers have been unable to generate funds for the capital investment required for storage buildings.

A wide range of crops are grown. Rotational cropping underpins all organic vegetable systems. As a result even a relatively large holding will have a wide range of crops which require different storage conditions. A grower running a box scheme tends to grow an even broader range of crops (up to 80 different species and varieties, with over 300 sowings in total is not uncommon). In addition, some growers supply several different types of market outlet and these will have different quality requirements. This confuses the issue when decisions need to be made about what type of storage to use and whether designated storage buildings are actually going to provide satisfactory storage as well as being cost effective.

Lack of financial and technical information. There is very little information on the fluctuation of wholesale market prices throughout the year, making it hard for growers to decide whether it is worthwhile to store. Very little information on the economics of storing conventional produce is available in a collated and published form, let alone for organic crops. Equally, the technical information on how to store crops organically has not been drawn together. Advisors and experienced growers often have knowledge and are willing to share it, but it is not readily available to other growers or conventional growers contemplating conversion.

2.2.3. Reasons why some organic growers do store

Some organic growers do store their produce using a range of techniques from clamps through to cold stores. Of the organic growers approached in this study none gave the reason that they stored crops because they expected to get a higher price for their produce out of season or for a better return from stored produce. The main reasons they gave for storage (and these should be considered by growers thinking about storing) were as follows:

- To achieve continuity of supply to their customers, especially if they were running a box scheme.
- To increase the quality of the produce reaching the consumer. Better storage can help maintain crop quality for a longer period of time.
- Consumers of box schemes wish to know how and where their food is grown and that it has been grown locally and then stored, rather than having produce which is bought in to ‘top up’ a box scheme (consumer confidence).
- To provide a regular income and thus avoid cash flow problems.
- To provide work for their staff all through the year.
- To avoid oversupply and saturation of the market at peak harvest time.
- To accumulate produce for peak periods of demand.

Short term cold storage of the more perishable crops can provide more efficient use of labour so that several days supply can be harvested at once (use of brought in labour for weekend harvesting can be avoided).

Produce brought in to supplement a growers own produce for a box scheme can be bought in larger batches and kept in good condition until it is distributed. This gains some economy of scale on deliveries and handling and enables buying in at a good price when the produce is still of good quality.

2.2.4. Perceived technical problems and problem crops

Conventional crops are often treated with pesticides during crop growth or postharvest to help prevent pests and diseases in storage. At the beginning of this study there were doubts as to whether long term storage of organic produce would be feasible. However, after evaluating information on the epidemiology of storage diseases and some of the trials done on the efficacy of pesticides, the situation for organic produce looks far more optimistic.

There are very few studies available comparing the storage of organically produced crops with conventional. There is some evidence, from West German studies, to suggest that organically produced crops actually store for longer. This is thought to be because crops grown organically have a slower growth rate and greater physiological maturity at harvest (Lampkin, 1990). Other studies (Abele, 1987) have shown that manuring did not affect storage under optimum storage conditions but at sub-optimum conditions of temperature and humidity differences emerged in favour of lower fertilizer levels. A study carried out by the PMB in 1986/87 revealed little difference in either the weight loss in storage or the percentage soft rotting of conventionally grown potatoes or organically produced ones when postharvest chemicals were not used (PMB, 1988). With the information available there appears to be little evidence that healthy organic vegetables will not store as well as healthy conventional ones.

However, it is probably inevitable that without the use of postharvest pesticides there may be higher losses during storage, although this will not always be the case. In other words there may be higher risk involved in storage of organic vegetables. Pesticides can only reduce crop losses; they rarely prevent them completely and are usually only applied as an insurance policy. Pesticides cannot replace good crop husbandry nor prevent deterioration of a poor quality crop already showing signs of disease. Trials on the use of postharvest pesticides quite often show that ensuring only undamaged crops go into store is more effective at reducing storage losses than the application of postharvest pesticides (Anon., 1991 & Davies, 1974).

Many of the problems associated with storage can be avoided by forward planning and practising good husbandry techniques. It is a common misconception that organic crops will automatically be more likely to develop storage diseases because they have not been treated chemically. In fact some of the storage diseases which are problematic for conventional growers are less likely to occur in organic crops. For example, soil borne diseases such as canker (*Phoma betae*) in beetroot and dry rot in potatoes are avoided by the relatively long crop rotations which organic growers use.

The nutrient status of the crop going into storage can also be important. Calcium deficiency, which can cause a physiological decay in a range of crops, could be important in organic systems on some soils. However, excesses of nutrients, for example nitrogen, are less likely in organic systems. This is associated with delayed maturity and increased susceptibility to damage at harvest leading to poorer storage in potatoes.

Optimum storage temperatures and humidities used to store conventional produce have been set to avoid storage diseases as well as physiological deterioration. If crops loose water and shrivel they are far more prone to storage rots. Many of the organisms causing storage rots are weak pathogens and can only infect and spread when the crop has lost its turgidity or has wounds through which they can enter. Consequently optimum conditions for the storage of most organic crops is likely to be the same as for conventional crops.

Conventional crops such as potatoes and onions are treated with sprout suppressants. To a certain extent choosing suitable varieties and using appropriate store temperatures make storage without the use of sprout suppressants feasible until April. As yet there are no acceptable alternatives to sprout suppressants to allow storage beyond this.

The main problem for organic growers is that they can only justify the cost of one store to service a wide range of crops. Some crops can be stored together as they have similar requirements for temperature and humidity (see section 2.3.14). Other crop combinations will have different optimum requirements. If the store can not be divided to allow different conditions then a compromise will have to be reached and some reduction in storage life must be expected. The main crops and the problems encountered when stored organically are:

Carrots. The problems for organic growers are similar to those encountered for conventional carrot growers. Refrigerated storage is required for long term storage of carrots until June. Unfortunately, cool stored carrots loose their skin finish and there is no technology available to prevent it. Consequently much of the conventional crop is stored in the field over winter. Field storage maintains good skin quality but is unreliable beyond March. Field storage can be a problem for organic growers because they are often on soils which are too heavy for successful field storage. Disposal or incorporation of straw used for extra insulation during field storage can be costly and affect nitrogen availability for following crops. An alternative low cost method to field storage needs to be found.

Parsnips. Parsnips can be stored successfully in the field but once they are removed from the soil and washed they suffer a rapid deterioration in colour which is a very noticeable problem for the pre-pack market. The crop needs to be harvested, washed and packed on the same day to ensure it reaches the shop without discolouring. This is also a problem for conventional produce and technology is not available to solve it.

Cabbage. This is one of the few organic crops where there can be periods of oversupply. With the increasing quality requirements of the supermarket trade, refrigeration is required for more than a few weeks storage. Organic cabbage is difficult to produce without some insect damage which can provide entry for storage rots, so much of the organic crop may be unsuitable for storage. Good crop husbandry and the use of insect proof fleece can help prevent damage in the first place but labour intensive trimming before and after storage may still be required. Much of the conventional crop is treated with fungicidal dips. Good management practice and ensuring only healthy crops are stored are the only organic alternatives available at present. The use of biological control agents may be possible in future.

Swedes. These can be field stored but there are very few organic growers on suitable soil types or who are in areas cool enough to store beyond March. Normally the price of swedes would not make it a worthwhile crop to cool store, but out of season swede (spring and early summer) fetches a good price in the supermarket trade and it would be worthwhile to develop a low cost storage method to enable growers who cannot field store to supply this market.

Onions. The technology for good onion storage is available but as with conventional onions the main problem is sprouting in long term storage i.e. beyond April. Appropriate store temperatures can help prevent sprouting but it is not as effective as using sprout suppressants in combination with refrigerated storage. Controlled atmosphere for long term storage can successfully prevent sprouting for storage beyond April and looks to be a very promising method for organic onions provided the method is eventually permitted by UKROFS.

Potatoes. Sprouting is the main problem associated with long term storage of potatoes beyond May. The technology is available for long term storage (until April/May) of the organic ware crop. Sprouting can be controlled by storing the crop at 3-4ºC. However, this is unsatisfactory for processing crops especially those destined for crisping; low temperatures induce sweetening resulting in an unacceptable deep fry colour.

2.3. STORAGE METHODS FOR ORGANIC VEGETABLES AND POTATOES

2.3.1. The physiology of storage

Harvested crops are still alive and biologically active. Respiration is one of the most important metabolic process concerned with storage. Carbohydrates are broken down by oxygen (with the help of enzymes) to produce carbon dioxide, water and heat. For successful storage, this process needs to be slowed down as much as possible without actually killing the crop. In this way water loss, weight loss, and excessive heat production can be minimised. Ripening, maturation and finally senescence also continue in storage leading to the natural decline of cells, gradually making the crop more vulnerable to fungal and bacterial storage rots.

Reducing the temperature of the produce tends to slow down all metabolic processes including respiration, and therefore prolongs the storage life of the crop. Excessive cooling however, will cause chilling, frosting, cell death and finally decay. Different crops have varying tolerance to cold temperatures and humidity and hence require different optimum storage regimes (see section 2.3.12).

Respiration can also be slowed down by reducing levels of oxygen and increasing levels of carbon dioxide in the storage atmosphere. When a crop is enclosed by any method, even in a sack or simple clamp, the crop itself respires. This increases the concentrations of carbon dioxide and decreases the concentration of oxygen within the store atmosphere. Controlled atmosphere stores work on this principle but the levels of these gases are regulated very carefully according to crop, variety and even the growth conditions of the crop (see Chapter 4).

Ethylene is another gas important in storage, affecting ripening, maturation and onset of cell death. It is produced by the crop itself, and some fungi and bacteria which cause storage rots. It can be removed from the store atmosphere using scrubbers to prolong storage life.

At present, organic vegetables and fruit are not stored in controlled atmosphere and its use has not been considered by UKROFS, therefore, strictly speaking it is not permitted by UK organic standards. However, controlled levels of oxygen, carbon dioxide and nitrogen are permitted according to the European Union (EU) and the International Federation of Organic Agricultural Movements (IFOAM) regulations and it is probable that UKROFS would consider controlled atmosphere storage as within keeping with the spirit of the standards (Crofts, 1997, UKROFS, pers. comm.). Removal of ethylene is not mentioned in EU or IFOAM standards, so no precedent has been set for its use. It is important that the status of all forms of controlled atmosphere for all crops is clarified in the UKROFS standards. This is especially the case for top fruit, where controlled atmosphere storage is the only option available to keep produce beyond 2-3 months to the high standards of quality required by the present market.

2.3.2. General good cultural and storage practice for organic field vegetables and potatoes

There are a number of general principles to consider whatever the type of crop to be stored and whatever the storage method is to be used, whether it be simply storing the crop in the field or using more sophisticated cool stores.

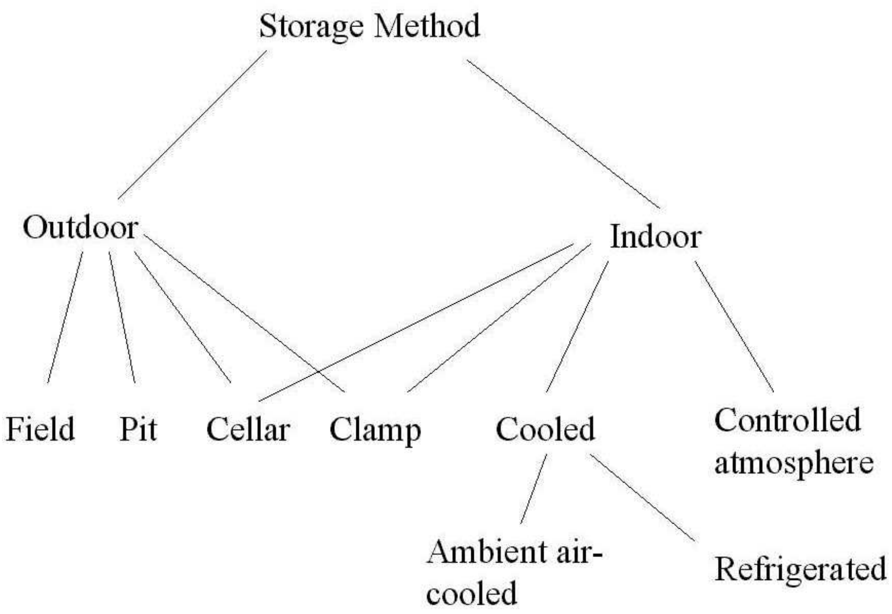
- **There must be a planned market for the produce.**
- **Decide which crops are to be stored from the start.** Use good quality seed, free of disease and choose varieties suitable for storage. Practice good crop husbandry to avoid pest and disease problems e.g. avoid overfeeding, practice crop rotations, cover carrots during growth to prevent carrot fly, and avoid erratic irrigation of root crops which causes cracking.
- **Harvest when the conditions are right.** Harvest in the cool of the morning, simply putting the harvested crop in the shade rather than leaving it in the sun can lengthen subsequent storage life. Do not harvest in the rain and never attempt to store a wet crop.
- **Handle the crop carefully during harvesting and storage.** Wounds and bruising promote water loss. Many storage diseases are caused by weak pathogens that can only enter a plant through a wound or when the plant is suffering from stress e.g. water loss, chilling or damage by another disease or pest. Hand grading is usually gentler than machine grading and may be feasible for small crop quantities.
- **Only store undamaged, good quality, healthy, pest and disease free produce.** Plant debris and excess soil should be avoided. A poor quality crop will always deteriorate more rapidly in store and quickly reach a stage where it is unmarketable.
- **Be clean and organised.** Harvesting and handling equipment should be serviced and clean. A cool store should also be clean and serviced so that it operates at the correct temperature. Ideally a store should be cleaned and given a period of rest to allow pests and fungal spores to die off. Keep track of what is going into the store and make sure it leaves!
- **Monitor the store.** Make sure that correct temperatures and humidities are maintained and keep a regular record of them. It is vital that the correct air flows are used in refrigerated and ambient air cooled stores. Make sure the correct stacking

distances are used in box stores. Inspect the store regularly for condensation. Free water on the crop allows many storage diseases to infect the crop and develop. Inspect the crop for disease and dispose of any affected material.

2.3.3. Choosing a suitable system

Organic vegetables can be stored using a wide variety of methods ranging from relatively simple and low cost clamps, to expensive and sophisticated controlled atmosphere stores. Figure 1 shows the methods which will be described in the following sections:

Figure 1 Storage methods



The methods chosen will be determined by a large number of factors the key ones being:

- **Resources available.** The necessary finance and materials to construct, and skills to operate the store.
- **Market supplied.** All markets require high quality vegetables, however, farm retailing, box schemes and processing markets are able to sell vegetables which do not have the very high standards of cosmetic appearance and size required by supermarkets. The standards required for box schemes can be achieved with simple methods such as clamps. Selling to supermarkets is likely to require refrigeration in order to maintain quality and appearance.
- **Type of vegetable.** Harder root vegetables will store satisfactorily in clamps, leafy vegetables will require refrigeration.
- **The value of the crop.** The more valuable the crop the more likely refrigerated storage will be financially viable.

- **Length of storage required.** Storage up until March can be achieved with clamps and ambient cooled storage. Beyond this point refrigeration will be required.
- **Volume.** The marketing of small volumes does not warrant the use of expensive storage technology.

Table 1 compares and summarises storage methods. The following sections give full descriptions, and assesses the advantages and disadvantages, of different storage methods and the circumstances where they are likely to be appropriate. Descriptions of several case studies and their cost are given in section 2.5.

2.3.4. Field storage

Here the crop is left in the field through the autumn and winter, harvest is delayed until the crop is required. The main advantages are simplicity and in some cases low cost. The main disadvantages are; the crop may be exposed to chilling and freezing, it remains exposed to pest and disease attack, harvesting can be impossible in bad weather, and the land remains occupied so that the planting of a new cash crop or fertility building crop is prevented or at least delayed. Usually only peat or sandy soils are suitable for field storage. Heavy soils such as clay are unsuitable, the ‘feet’ of the crop may become water logged and rot, and marketing opportunities may be missed because the land is too wet to allow harvesting. It is often the case that organic growers are on heavy soils so that field storage is not an option. For others it may be viable, especially for those supplying box schemes or for those growing carrots where field storage is currently the best option.

It is beneficial to have shelter belts or hedges at the field boundaries where field storage is contemplated. This helps to prevent cold winds sweeping across the field which accentuate freeze thawing cycles. The conservation and management of field boundaries is also an integral part of organic management practice.

Crops suitable for field storage

Field storage can be appropriate for some root crops. Cabbages can also be left to stand in the field until just before the first frosts strike.

Carrots. Field storage is an important way of storing carrots. The visual quality of field stored carrots is much better than that of cool stored carrots. Consequently, the method of storage for most conventional carrots is in the field. This option is generally viable up until March and can be at low cost if straw for extra insulation is not required. On well insulated soils, such as peat, carrots can simply be ridged up to prevent frost reaching the roots. In colder areas and on poor insulating sandy soils, a layer of straw or a layer of black polythene followed by a layer of straw is required. This can prove much more expensive. A product made from recycled paper is also being developed to replace black polythene, it should prove to be of similar cost (Rickard, 1996, pers. comm.). A further draw back if straw

Table 1 Comparison of the main vegetables storage systems

	OUTDOOR		INDOOR				
			Ambient cooled		**Refrigeration**		**CA storage**
	Field stored	**Clamps**	**Convection ventilation**	**Forced ventilation**	**Convection refrigeration**	**With humidifying**	
Length of storage	until March	until March	until March	until March	weeks*	until March/April	June/July**
Most suitable type of vegetable	carrot, parsnip, cabbage, leek, swede	potato, onion, swede, beetroot	potato, onion	potato, onion	most vegetables	most vegetables	fruit, cabbage, onion
Market outlet	Depends on crop	Box scheme, farm shop, wholesale	Box scheme, farm shop, wholesale	Box scheme, farm shop, wholesale	Supermarkets, box schemes and wholesale	Supermarkets, box schemes and wholesale	Supermarket
Skill in operating	low	low	low	medium	medium	high	high
Control of quality	low-medium	low-medium	low	medium	high	very high	very high
Suitable for box storage	-	yes	yes	yes	yes	yes	yes
Weight loss	minimal	minimal	medium	high	very high	minimal	minimal
Temp control	minimal	minimal	low		high	high	high
Ability to store crops together	-	medium	medium	medium	good	good	none
Capital costs	none	low	medium	medium	high	high	extremely high
Annual costs	can be high***	low	medium	medium	high	high	extremely high

* Conventional refrigeration without humidifying systems is not recommended for long term storage
** Some crops will store for up to one year in CA stores
*** e.g. costs of straw and polythene for field stored carrots can be high.

is necessary, is the cost of its disposal or incorporation into the soil. Incorporation of straw can also cause ‘nutrient lock-up’ whilst it breaks down (For further details see section 2.4.3.4 and section 2.5.2 Case Study 1 for costs.)

Parsnips are not as frost sensitive as carrots and can be left in the field, usually without covering, until they are required. In most areas they will remain in good condition until the end of April (ADAS, 1984a).

Swedes are usually left in the ground until required, varieties with higher dry matter content generally keep better. In very cold weather swedes can rot at the neck.

Turnips can be field stored until spring by covering them with earth using a double mould-board ridging plough between the rows (ADAS, 1941).

Winter white cabbages can be left to stand in the field in mild areas or places that have dry maritime conditions. However, this is regarded as a high risk practice as winter white cabbage cannot tolerate mild frosts. These varieties are more appropriate for putting into store for the supermarket trade. It is recommended that winter white cabbages should normally be harvested and in store by mid-November or early December in milder areas (ADAS,1984a) (For further details see section 2.4.6.3)

Chinese cabbage can be held in the field until November/early December or until the first severe frosts (ADAS, 1984c).

There are also a range of **crops which can be grown outside during the winter** to help fill gaps in supply especially for box schemes and farm shops which run all year round. These include:

Kale - which crops all through the winter

Sprouting broccoli - which grows over the winter and is ready in March/April

Cabbage (savoy, savoy hybrids and January King types) - Some varieties of cabbage can be grown outside over the winter. Again these are most suitable for box schemes or for supplying farm shops as they usually suffer leaf damage during cycles of freezing and thawing and require a lot of trimming at harvest. Savoy and savoy hybrid types (e.g. Celtic and Tundra) and January King are best known for their standing over winter and can be harvested from November through to February. By March the cabbage tend to bolt. Generally these cabbages do better in colder areas of the country as milder weather tends to cause more cycles of freezing and thawing and more rots.

Chinese leaves - which can be grown in polythene tunnels or covered with fleece during cold weather.

Leeks - some varieties tolerate standing over the winter and can be harvested until March or April.

Winter hardy cauliflower - Some varieties can stand over winter to be harvested from March until June.

2.3.5. Cellars

Cellars, often under houses, other buildings or built into hillsides have been traditionally used in Europe but are little used at present. They are either below or partly below ground and as a result are well insulated. Consequently, their temperature remains fairly stable (approximately 11°C), protecting the stored crop from freezing or excessive warmth (Bubel & Bubel, 1979).

It is unlikely that any grower would contemplate building a cellar from scratch, the main limitations being extra expense of building a structure below ground (strong retaining walls and a strong roof) and the effort involved in loading and unloading below ground. Cellars are still sometimes used in parts of the world where temperatures are extremely cold during the winter and building a store below ground helps to prevent the crop from freezing. The temperatures experienced in Britain during the winter do not usually warrant the use of underground storage, clamps provide a simpler alternative. It is possible to fit ventilation or refrigeration equipment to a cellar and there must be some benefit gained from lower cooling costs than for an above ground store but higher building costs probably out-weigh this option. Information comparing the costs of cellar storage with above ground storage has not been found.

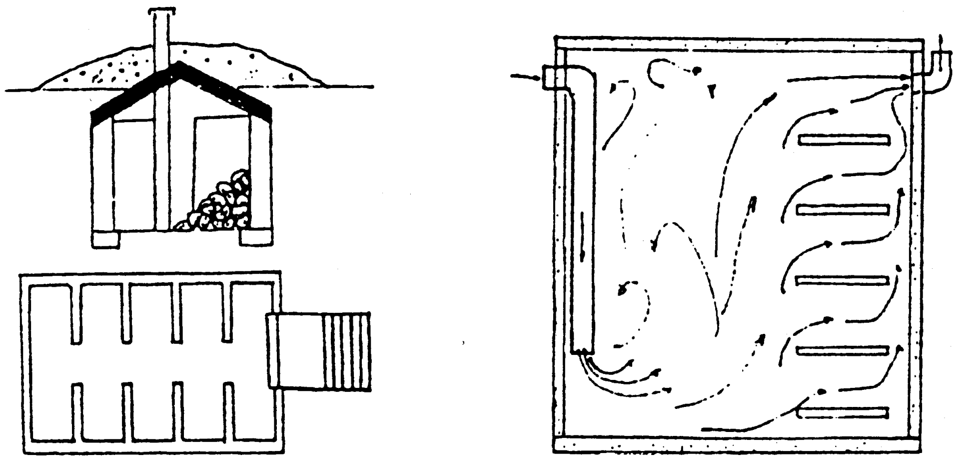
However, if a cellar is available, below a house for example, it is suitable for storing small quantities of crops such as cabbages, onions and potatoes (also pumpkins as long as the temperature is kept above 10ºC) over the winter quite successfully until March, or for a few weeks during the summer.

The crops should be spread out thinly on shelves or in shallow slatted boxes to ensure good air circulation. Onions and garlic can be plaited into bunches and suspended from the ceiling. Drying out can be a problem, dirt floors rather than those of stone or concrete help maintain humidity. Alternatively the floor can be sprinkled with water, pans of water placed on the floor, or boxes of produce covered with damp (not wet) open weave sacking (‘burlap’).

Temperature and humidity should be measured inside and outside the store using thermometers and a hygrometer. Optimum temperatures and humidity are unlikely to be achieved without the addition of proper venting and refrigeration, but some temperature control can be gained simply by opening vents, windows or doors to allow cooler or warmer outside air into the store as required. In this way it is possible to lower the temperature within the cellar to around 4-5ºC for a significant proportion of the winter.

A well constructed cellar allows the air to circulate by convection. The shelves should be a few inches away from the cellar walls to allow air to circulate and prevent moulds (see Figure 2) (Bubel & Bubel, 1979).

Figure 2 Cellar store and air circulation around shelves



(Drawing adapted from Bubel & Bubel, 1979)

Other factors which are important to consider if building a cellar are; that the soil drainage must be good (cellars on the north side of a building or hillside will remain cooler than on the south side), there must be some means of ventilation, it should be accessible in all weathers and have good steps or a hoist for easy loading and unloading. For further information on building cellars for storage see Bubel & Bubel (1979).

2.3.6. Pits

Pits or trenches can be dug to store crops in bulk or in boxes until March. As with cellars use is made of the relatively stable but cool temperatures below ground. The simplest form is a pit dug on a high point in the field to prevent water collecting inside. The pit can then be lined with straw or other organic material, filled with the crop to be stored and then covered with soil (up to 25cm thick for cold climates) or a layer of organic material such as straw. The main problem with pits is their lack of ventilation, which can lead to rotting. Ventilation can be achieved by digging ventilation trenches down to the base of the store or leaving ventilation holes at the top. The ventilation holes need to be covered with straw in such a way as to allow air through but not rain (Thompson, 1996).

Alternatively the store can be partially in a pit and can be extended upwards by creating walls of banked up soil above the pit. Over this can be placed a ridge-roof made out of poles and wire netting, covered with a layer of straw followed by soil. Ventilation holes, which can be covered in severe weather, can be left in the roof (Burton, 1948).

Pits have many of the disadvantages associated with clamps such as high labour requirements for construction, loading and unloading (which can only take place in good dry weather). In addition it is harder to provide ventilation in a pit. Care also has to be taken that the pit is dug on a well drained site and at the top of any undulations in the ground.

There may be an advantage in using pits rather than clamps for storage of carrots which require high humidity and should remain in contact with soil to maintain good skin finish. This may provide a viable alternative to field storage. As yet, examples of storing carrots in this manner have not been found in literature searches or in practice by growers.

Another adaptation of the pit is to load root vegetables (e.g. carrots & potatoes) into bulk plastic bags (e.g. silage bags) and place these in a semi-permanent pit. Provided a front end loader for a tractor is available labour involved in loading and unloading would be substantially reduced. Netting followed by a layer of straw could be placed on top for extra insulation during cold periods. However, as far as is known this method has not been tried in the UK and would need some development work.

2.3.7. Clamps

Simple clamps, (also known as pies, graves, hogs or caves) have been used for storage of vegetables and fruit for centuries. Cool storage has largely made the use of clamps obsolete in conventional production but they could provide a suitable form of storage for organic growers, especially those running box schemes, who are beginning to contemplate storage but are not at the stage of committing themselves financially to more sophisticated stores requiring higher capital investment. Decisions to build clamps can be made at harvest time and are therefore suitable where growers suddenly find that they are in the position where they need to store or have an unexpectedly good crop suitable for storage.

Organic growers have had mixed success with clamps. Ambient temperatures, varieties, harvesting methods, maturity of the crop, conditions at harvest, pest and disease levels on the crop, methods of construction, expectations about the length of the storage period, and the growers experience all affect the success of this type of storage. There has been quite a lot of work on using vented clamps, and they may be of benefit for indoor clamps, but there is little evidence to suggest that for outdoor use they are better than unvented clamps.

Much of the information available on clamps is relatively old and the research was done before the widespread use of pesticides during crop growth or postharvest. It is therefore felt that much of this information is of direct relevance to organic production and storage. Having said this, it is critical that only crops that are in good condition and apparently free of pests and diseases should be stored this way. Temperatures in clamps often rise above 10ºC for short periods providing suitable conditions for many diseases to develop.

The most suitable crops to store using clamps are hard vegetables, such as potatoes, carrots, beetroot, turnips, swedes, celeriac and parsnips. Clamp storage is hardly a precise science but usually these crops can be stored this way for two to three months i.e. until

Christmas. Crops which do not tend to sprout are stored reasonably successfully by many growers up until March or even April, if weather conditions are favourable. Beyond this clamp storage is not suitable as ambient temperatures rise and increased levels of shrivelling and rotting occur.

Clamps can be constructed outside or inside a building such as a barn, shed, or lean-to. There are various methods of construction some of which are suitable for outdoor use while others are better for building indoors.

Outdoor

- Crop covered by loose straw followed by soil (traditional, unvented).
- Crop covered by soil alone if frost can be kept out (traditional, unvented).
- Clamp walls made with straw bales, netting and loose straw used to cover the top (improved, unvented).
- Crop lined with polythene covered by straw bales ventilated with wire mesh ducts (improved, vented).
- Crop stored in pallet boxes lined with polythene sheets covered with straw bales and ventilated using wire mesh, ducts placed in amongst and above the crop (improved, vented).

Indoor

- Crop covered with soil alone (traditional, unvented)
- Crop covered with loose straw only (traditional, unvented).
- Clamp walls made with straw bales, bales or netting and straw used to cover top (improved, unvented)
- Crop covered with loose straw or if risk of frost polythene, lined sides and straw (improved, unvented).
- Crop stored in pallet boxes lined with polythene sheets covered with straw bales by making use of the pallet base to form air channels for ventilation (improved, vented).

See Table 2 for advantages and disadvantages of clamp storage.

Table 2 Advantages and disadvantages of using clamps

Advantages	Disadvantages
• Capital cost is low as relatively minimal quantities of materials are needed but straw needs to be applied annually. • Not technically difficult to build. • No running costs once constructed. • Condensation is not normally a problem. • Can be sited close to harvested crop giving storage flexibility to the farmer especially at busy harvest times (outdoor clamps). • Different vegetables can be stored together. • Flexible system so that farmer can delay decision to store until harvest time. • Suitable for use with direct marketing such as box schemes.	• Temperature control is minimal and is mainly by conduction. • Is usually insulated against the severest expected frost which may not arrive often resulting in unnecessarily high storage temperatures and possibly rotting. • Reasonably high labour requirements for construction of clamps as they need to be built every year and re-made during loading and unloading of produce. • Inspection during storage is not really practical as the earth and straw is time consuming to remove and replace. • De-sprouting (e.g. of potatoes) by hand maybe necessary depending on the length of the storage period. • Loading/unloading operations cannot be carried out in rain or heavy frost (outdoor clamps). • Frost and rodent damage is likely. • Can only be constructed on well drained land (outside). • Final product may be of low quality.

In the past different vegetables have been stored together in clamps. This is probably most useful for small growers running box schemes, or farm shops who want to store vegetables for a short period of time. The length of storage period will probably be shortened because respiration gases and ethylene produced by the different crops will affect one another (see section 2.3.14 for crops which can be stored together). If the marketing of the produce is well planned and the amount of produce needed at a particular time is known, batches of different crops can be put together in small clamps and only one clamp needs to be opened at a time, saving labour to open and close several clamps each week. Netting the crops will help keep the different crops separate and assist with removal from the clamps.

The costs of clamps varies from approximately £2/tonne for outdoor clamps to £7/tonne for a ventilated clamp and up to £12/tonne for an indoor clamp. For more details see section 2.5. Case Studies 2-4.

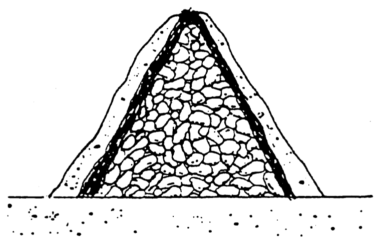
2.3.7.1. *Traditional unvented, outdoor clamps*

Siting of clamps. The simplest form of clamp is a crop piled on an area of land at the side of a field where the ground is not subject to water logging. The pile can be positioned either directly on the ground or in a pit. Ideally the pile should be constructed on sloping land, or a trench can be dug around the clamp to improve drainage and a layer of straw placed underneath the pile. Ideally the clamp should be orientated in parallel to the wind (Burton, 1948) and in a sheltered position but not too close to buildings, or rats will find the crop easily. Avoid building the clamp on the same spot every year and remove any crop debris from the area which may harbour pests and diseases. Constructing the clamp on a concrete pad can help with unloading and loading especially where this is done by machine.

Crop pile dimensions The base of the pile can range from about 1.2m for high respiring crops and 1.8m for low respiring crops (Rickard, 1997, pers. comm.). The width of the base should be marked out before constructing the pile. The length of the pile can be as long as required. The height of the pile can range from 1-2m, depending on the width of the base, the tendency of the crop to roll downwards, its tendency to heat due to respiration, and its susceptibility to compression damage. See Table 3 for pile dimensions of different crops.

Loading the clamp As with all clamps it is important that the crop goes into the clamp when it is as cool as possible. Harvest in the morning and leave root crops in the ground for as long as possible into the autumn but before wet weather makes harvesting impossible. For most crops covering the heap should be delayed for up to about a week to allow the crop to dissipate any field heat. Most crops respire quite rapidly for the first few days after harvest. Without cool storage the heat generated can not be removed quickly. If conditions remain mild, the clamp is best left uncovered until cold weather strikes. Care should be taken that white cabbages and potatoes are covered with a light excluding layer, as if they are left for longer than a day in light this causes greening.

Figure 3 Simple outdoor unvented clamp



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Covering the clamp. Most crops can be covered with a layer of loose straw to keep humidity high within the pile and to protect it from frost. Use stiff straw such as wheat followed later by a layer of soil when cold weather is expected. Often the top of the ridge is left soil free and a thinner layer of straw used to allow some ventilation. This also helps prevent soil dropping down into the crop where this is undesirable. In colder weather the top of the ridge can also be covered in soil. The thickness of the layers of straw and soil depend upon expected air temperatures and cooling by wind, the sensitivity of the crop to frost, and the heat produced by the crop itself. Different soils also have different insulation properties, for example sandy soil will need to be laid more thickly. Heavy clay soil can be problematic as it sticks together in clods making it hard to cover the vegetables and can set making it difficult to dig away at unloading.

Table 3 Summary of clamp storage methods

Crop	Type of clamp	Crop pile dimensions		Capacity	Insulation	Lining	Extra ventilation	Comments
		Base (m)	Height (m)					
Beetroot (a)	Traditional outside unvented	1.5	1.4	Theoretically unlimited. In practice up to 2t as too much labour moving soil	0.15m loose straw followed by 0.3m soil	None	Leave apex clear for a few days to allow cooling before closing clamp. Do not use straw chimneys.	If frost not a problem, better to use soil only (0.15m to 0.2m thick)
Beetroot (b)	Improved outside vented	1.8	1.5	No limit	Straw bales	500g polythene to within 0.3m of ridge	Open ended ducts of wire mesh running length of clamp, two on ground, one on apex are recommended	Can use without ventilation. Do not use straw chimneys
Beetroot (c)	Improved outside in pallet boxes	0.5-1t pallet boxes		No limit	Straw bales	Polythene to line boxes	Slatted bottoms of boxes used as vent channels	Boxes may also be stacked 2-3 high, built around with straw and covered with polythene (ridge must be left clear)
Beetroot (d) Carrots and other crops*	Improved inside in pallet boxes	1t pallet boxes (single depth only)		No limit	0.6m loose straw on top (absorbs condensation)	Polythene	Pallet base forms ventilaition channels	If danger of frosts, line sides with polythene and straw bales *Can be used for other crops, but without polythene lining
Beetroot (e)	Improved inside	1.8 - 2.1m	1.5m	No limit	0.6m loose straw on top (absorbs condensation)	Polythene	Welded mesh ducts	If danger of frosts, line sides with polythene and straw bales. Piles of more than 1.8 - 2.1m wide and 1.5m high require fan assisted ambient air cooling
Cabbage (a) winter white	Inside traditional	-	up to 2.4m	Unlimited	Cover only if severe frosts threaten and then remove	None	Mesh ducts required if height more than 1.5m	
Cabbage (b) winter white	Inside inboxes pallet or boxes	Up to 1 t boxes		Unlimited	Cover only when severe frosts threaten and then remove	None	Possible to just stack boxes in airy but frost free barn. But intermitent blowing with cool ambient air an advantage	
Carrots	Outside traditional unvented	1.5	1.3	Theoretically unlimited in practise up to 2t as too much labour moving soil	Preferably just soil 0.15m to 0.2m thick	None	None	For small quantities placing crop in nets makes retrieval easier

Crop	Type of clamp	Crop pile dimensions		Capacity	Insulation	Lining	Extra ventilation	Comments
		Base (m)	Height (m)					
Onions (a)	Traditional inside	Nets (25-50kg capacity) loosely stacked to 'safe' height		Unlimited	Cover with straw or quilt if severe frosts threaten	None	Onions benefit from plenty of air circulation. Construct stack on pallets or wooden slats	
Onions (b)	Temporary outside 'windbreak'	Wooden frame work 2m high by 1.5m wide		Unlimited	Straw on top half of heap only followed by polythene	None	Wind blows through sides	An adaption of this is to simply leave the onions stacked in trays outside
Potato (a)	Traditional unvented outside	1.2-1.8	High as possible	Up to 2t otherwise too much labour moving soil		None	Through straw in ridge (none)	Cover with more soil to about 0.2m when severe weather threatens and after crop has cooled. After Jan/Feb tubers need desprouting before sale
Potato (b) Swedes, Carrots, Turnips and Beetroot	Straw bale clamp outside	bales 1.8-2.4m apart	piled up to a ridge in middle	20-40t	Small straw bales for walls 2 bales high. Top covered with net followed by loose straw 0.3m thick	None (beetroot and carrot cover with polythene before straw bales)		
Potato (c)	Improved inside	1.8-2.1	1.5	unlimited	0.15m straw and 0.1m earth for down to -5ºc		Straw covering ridge only	
Swede (a)	Traditional outside unvented	1.8	1.5	Up to 2t or movement of soil too labour intensive	0.3m loose straw followed by 0.15m soil. Leave ridge free of soil	None	None. Leave ridge free of soil	Swedes best stored under soil alone if practical ie: for small quantities
Swede (b)	See potato (b)							
Swede (c)	Traditional outside	Packed into nets and stacked		Up to 2t	0.3m loose straw	None	None	Best constructed outside or tends to dry out
Turnip	Traditional outside	2.1	1.1-2.1		0.3m loose straw followed by 0.05-0.1m soil	None	None. Leave ridge free of straw	

Loose wheat or Rye straw are best for covering clamps, long lengths of straw bent over ridge. Cover ridge with soil in severe weather.

Traditionally potatoes were covered with 0.15m of straw followed by a thin layer of earth just thick enough to hold the straw down. Once the temperature of the potatoes dropped between 7 and 9ºC and severe weather was imminent a thicker layer of soil was placed over the existing layer (Watson & More, 1949). A layer of straw 0.15m thick followed by a layer of loam 0.1m thick is sufficient to protect potatoes against frost down to -5°C (Burton, 1948). A 0.25m layer of straw followed by 0.15m of loam will protect potatoes down to -20°C (Burton, 1948). A layer of loose straw or bracken 0.3m thick followed by a 0.1 m layer of soil on the sides exposed to the prevailing wind is sufficient to protect turnips (ADAS, 1941). See Table 3 for suitable layers of straw and soil for other crops.

Loam is one of the best and simplest materials to cover a clamp. If ambient conditions are not too cold soil provides a better cover than straw, for crops such as carrots (ADAS, 1980), swede and potatoes (Burton, 1948) Less rotting occurs in clamps covered with soil alone. This is borne out by recent grower experience. Carrots clamped under straw alone rotted more readily than those under a layer of soil (Schnabel, 1997, pers. comm.). A possible explanation, which is unproven, is that straw allows too much humidity to escape. The carrots loose turgidity, which then makes them vulnerable to attack by fungal and bacterial rots. Average temperatures in a soil covered clamp are also likely to be lower, therefore fungi and bacteria do not spread or multiply so rapidly.

The main drawback with using loam is that it is very labour intensive and requires large quantities of soil. It is really only practical to use on up to 2 tonnes of crop. A layer of soil 0.15m to 0.2m thick is required which can become a substantial amount of soil on larger clamps. The amount of loam used is also a problem on clamps which use a combination of straw and soil. Once the soil has been dug out it loses its structure so it cannot necessarily be returned to the field.

A primary drawback with clamping is that the clamp is usually insulated to provide protection from the coldest weather expected. This means that temperatures are likely to be higher than necessary within the clamp. The internal temperature will depend upon external fluctuations, wind speed and the heat generated by the crop itself. Temperatures also vary according to position inside the clamp. There is little information on the temperatures encountered inside clamps but one example quotes that the average temperature inside a British potato clamp during the winter of 1935/36 was 4-6.5°C (Burton, 1948). It may be better if thinner layers of straw and earth are applied early on in the autumn and additional layers applied when colder weather is expected. In milder areas a covering of soil is all that is required for the whole of the winter.

A second drawback of using clamps is the time taken to unload the crop. It can be very time consuming searching for and then grading the crop out from the soil and straw before marketing. For smaller quantities of crop to be loaded and unloaded by hand, it is advisable to place the crop in net bags (made of non-rotting material). Once it comes to unloading, the corners of the bags can be grasped and pulled from the straw and earth (Schnabel, 1997 pers. comm.). For larger quantities of crop a net of non-rotting synthetic material used to cover the crop under the layer of straw may prove useful. This can then be pealed back to assist unloading.

Straw bales to cover outdoor clamps. To save on labour costs outdoor clamps can be constructed using straw bale walls with a net and layer of straw for the roof. This method has proved successful for 20-40 tonnes of crop. Access is relatively easy and even though polythene is not used the crop does not seem to get too wet and air can circulate between the gaps in the bales (Tolhurst, 1997, pers. comm.).

Improved clamp using straw bales and boxes. A similar method to that described in section 2.3.7.5 can also be used outside.

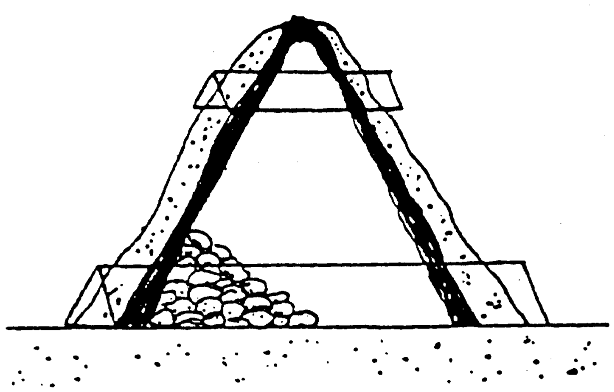
2.3.7.2.Traditional vented, outdoor clamps

There appears to be little evidence to suggest that vented outdoor clamps are better than unvented. Some traditional methods of venting are mentioned here because they may be of some benefit if the crop has to be covered when the pile is first built. They can help field heat to escape. The vents can then be blocked off.

Straw chimneys. Many crops respire quite heavily for the first few days after harvest and it can be beneficial to construct a column of straw up through the centre of the clamp as it is being made. However, this can cause condensation to collect on the crop immediately surrounding the straw and its use is not advised for potatoes (Burton, 1948) and beetroot (ADAS, 1983).

Venting boards Two boards can be nailed together to form an inverted ‘V’ and placed over the ridge or at the base of the pile to assist ventilation. The boards need to be sufficiently long to extend beyond the straw and soil covering the pile (Figure 4).

Figure 4 Simple clamp with vent boards



2.3.7.3. Indoor traditional clamp

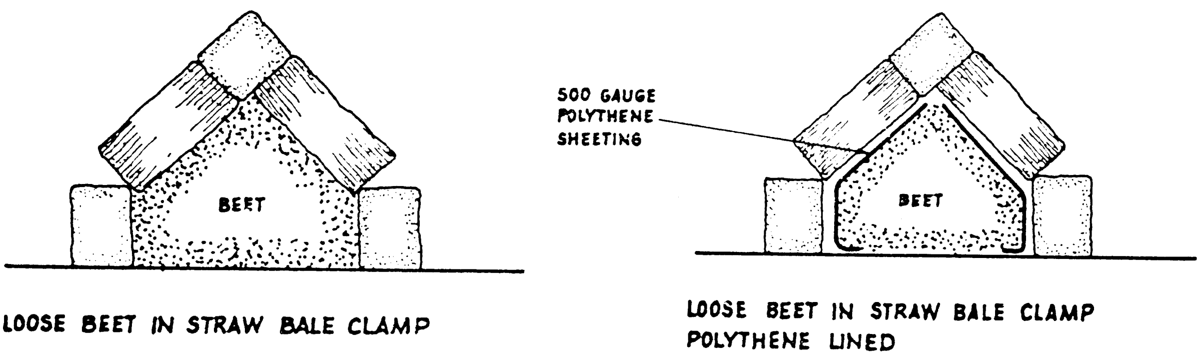
Traditional clamps can also be constructed indoors e.g. in a barn. Soil is not commonly used for practical reasons instead a layer of loose straw 0.6m thick can be laid over the pile to absorb condensation. During periods when there is a danger of frost damage the sides of the heaps need to be lined with polythene and straw bales. The use of a welded wire mesh ventilation duct is recommended (ADAS, 1983).

2.3.7.4. Improved clamp (bulk storage)

The use of improved clamps has been researched for beetroot in the late 1960's (Chrimes, 1970) and 1970's (Davies *et al.*, 1976) but organic growers successfully use these methods for other crops. Usually these types of clamps are constructed in a barn or lean-to where the use of loose straw and soil to cover the crop is messy or impractical.

Improved clamps are built using small traditional straw bales rather than loose straw and soil. Bales are quicker and easier to move about at loading and unloading. It can be difficult though to pack the bales together to get good coverage of the crop and create a good seal. To keep humidity high within the clamp and reduce desiccation of the crop, a layer of 500g polythene can be placed over the pile leaving a 30cm gap for ventilation at the ridge , see Figure 5 (Chrimes, 1970).

Figure 5 Straw bale clamps



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A 'Dickie Pie' (usually constructed outdoors and used for potatoes in the past, but can be used indoors) is a form of improved clamp built with straw bales and polythene, where ventilation ducts are built into the crop pile. The ducts are usually made of wire mesh which are run along the length of the clamp and are open at both ends. For beetroot, two ducts are placed on the ground and one at the apex (ADAS, 1983). A similar construction can be used for potatoes. The ducts allow warm air to be removed by convection and temperatures are generally lower by 2-3ºC within a clamp of potatoes of this type compared to a non-vented clamp (PMB, 1967).

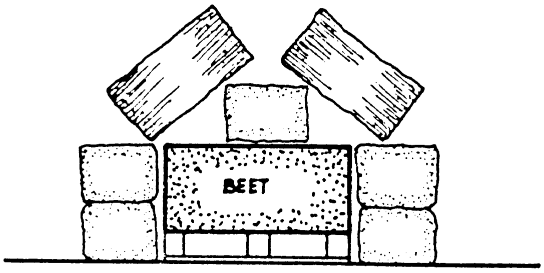
Fans can be fitted to the ventilation ducts running through clamps, this is especially useful indoors. When outside ambient air is at a suitable temperature and humidity, air can be blown through the clamp to cool it down. In the case of onions and potatoes the crop can be piled over the ducts and warm air blown through for curing. Straw or other insulating material can then be placed on top once the crop has cooled.

2.3.7.5. Improved clamps using bulk pallet boxes

If fork lift attachments to a tractor are available, ease of handling can be further improved by storing the crop in pallet boxes. Pallet boxes can be used in improved clamps outside or indoors (see Figure 6). The crop is placed in 0.5-1 tonne boxes, and a single row of boxes is covered with bales of straw. Quality of the crop is improved if the boxes are lined with polythene sheeting (ADAS, 1983).

In his experiments in 1971 storing beetroot in clamps Chrimes (1970) used pallet based bulk bins (1.1m x 1.1m x 0.5m) with a capacity of 270kg of roots. The boxes had solid sides and bottoms, with a ventilation equivalent to 4% of the lower surface area provided by slots cut out of the angle between side and bottom. The bins were lined with 500g polythene with a 30cm gap left along the crest of the ridge to aid ventilation. This was then covered with straw bales. The trial provided good results with 90% of the roots marketable in early July, and in very good condition.

Figure 6 Pallet box storage in an improved straw bale clamp.



BULK BIN CONTAINING BEET IN STRAW BALE CLAMP

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The pallet boxes can also be stacked two or three high, built around with straw and covered with polythene or some other cover to protect it from the rain. The ridge must be left clear to aid ventilation. The base of the pallet boxes form a channel so additional ventilation ducts are not needed (ADAS, 1983).

Clamp storage methods are summarised in Table 3.

2.3.7.6.Simple forms of indoor storage

Many farms have an existing barn which can be used for both temporary and long term storage. Most rain-proof buildings can provide a basic store. Preferably the building should have insulation. e.g. straw bales, a proprietary insulation board, panels or foam. Bubble wrap polythene is a cheap alternative that can provide some insulation e.g. for a small shed.

A Dutch barn can be made from a simple pole barn (a roof supported by poles) by making walls with straw bales. They are relatively cheap (see section 2.5, Case Study 4) and can provide a suitable indoor area for clamps. A disadvantage is that straw bales occupy valuable storage space. Alternatively a small barn/store can be constructed for £5,000-£10,000, for more details of costs see section 2.5, Case Study 4.

Straw bale buildings. Another more novel form of low cost building is made almost entirely of large straw bales on a concrete pad. This type of construction can be made to comply with building regulations and planning permission. The walls are made of straw bales pinned together with hazel or metal rods and rendered inside and out. Timbers are used to construct the roof. Straw is a very good insulator, so this type of building could potentially make a store and can be fitted with vents, fans and temperature monitors. As far as is known no-one has tried making this type of store in the UK (Tolhurst, 1997, pers. comm.).

Short term indoor clamps. Some small organic growers successfully store a range of root vegetables from 6 weeks to 3 months in adapted clamps within a barn. Produce is best stored loose in bulk boxes but often the produce is bagged and raised off the ground by placing the bags on upturned potato trays or slatted pallet boxes. This helps to prevent moisture soaking into the bottom of the bag causing the bottom to drop out The bags are stacked together, just one layer thick is best, and then covered with straw or other insulating material. The clamp is unloaded as required or when the crop starts to deteriorate (e.g. sprouting or rotting).

Potato quilt. Potato quilts were originally designed to insulate the top of bulk potato stores but they can be used indoors to cover any crop. They are very useful to cover short term clamps where frequent access is required e.g. for box schemes and farm shops. Trident Potato Quilts can be obtained from Offshoot Ltd (1996) and other suppliers and cost about £12/m^2. The potato quilt is 2.5cm thick and provides thermal insulation equivalent to a 45cm covering of loose straw. This reduces labour and is effective down to -10° C and also allows easier access to inspect crop (Chapman, 1996, pers. comm.).

2.3.8. Cool storage (ambient air cooled and refrigerated)

In cool storage, temperature and humidity can be regulated with greater accuracy and storage life prolonged. Before the various methods are described some general points on avoiding condensation in stores and monitoring temperatures will be addressed.

2.3.8.1 Controlling condensation problems in store

The stored crop is continually producing water vapour and the surrounding air also contains moisture. Condensation is caused where there is some form of temperature gradient i.e. where air meets cooler air or a cold surface . There are two main forms which can cause problems in store. Structural condensation and stack condensation.

Structural condensation occurs where moisture condenses onto the inner surface of a building and then drips onto the crop. The degree of condensation depends on the temperature difference between the inside and outside of the store and the amount of insulation the store building has, particularly in the roof. Ways of avoiding structural condensation are to:

- Insulate the building.
- Ventilate the top of the store to get rid of warm moist air. Ventilate when the air outside is at relatively low humidity (e.g. in the early afternoon during winter) and is at a similar temperature to the crop.
- Cover the top of the store with a loose layer of straw (approx. 0.5m thick for potatoes) to absorb water dripping onto the crop. Laying a net over the crop first, makes removing the straw easier when the time comes to unload.

Stack condensation occurs where moisture condenses within the stored crop, usually in the very top layers where the temperature is cooler than in the rest of the stack. Stack condensation can be avoided by:

- Having a well insulated roof, so that the top of the crop looses less heat.
- If there is no roof insulation it is essential to cover the stack with a loose layer of straw, 0.5m thick. It is important to apply the straw daily while the stack is being filled, the risk of condensation is highest at this time because the crop temperatures coming off the field are warmer than those already in the store.
- Using roof space heating.
- Re-circulating air through the stack to reduce temperature gradients between the top and bottom of the stored crop.

Condensation is likely to occur around doorways, make sure there is adequate insulation around the door. Keep down the number of times a cool store is entered. Special plastic curtains may be a sensible option in a store that has to be entered frequently. It helps prevent condensation, and restricts the loss of cool air, keeping running costs down.

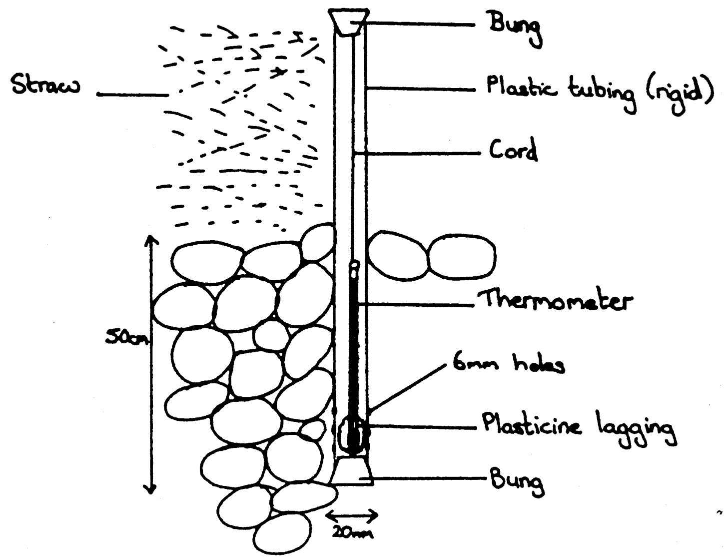
2.3.8.2. Monitoring temperature in stores

It is useful to be able to monitor temperatures in simple stores such as clamps but it is vital to the correct running of refrigerated and ambient air cooled stores. Not only is this essential for temperature regulation but it is also important to record temperatures in the store so that any problems can be detected quickly. The temperature above the crop should be monitored as well as the temperature within the stored crop. Above the crop a maximum - minimum thermometer should be used. Temperatures within the crop can be measured using a thermometer which needs to be installed in the crop during loading.

A low cost device designed for use in potato bulk stores (PMB, 1996b) can also be used for other vegetables and can be buried in bulk boxes as they are loaded (see Figure 7). A cord is attached to the top end of a general purpose thermometer (preferably not mercury, in case there is a breakage and the crop is contaminated). This is placed inside a rigid plastic tube (20mm in diameter and at least 1m in length) in which a few 6 mm holes have been drilled near the lower end. The tube should be stoppered at both ends. It is useful to have the cord attached to the bung that goes in the top, so that the thermometer does not fall and break if the stopper is taken out by mistake. The bottom of the tube should be about 50cm below the surface of the crop, which is normally the warmest place in the store. The thermometer bulb should be lagged with some plasticine to prevent the temperature changing during reading.

Where possible it is also desirable to have another thermometer near the bottom of the store to keep an eye on the temperature gradient within the store. For large stores it is recommended to have a thermometer for every 50-100 tonnes of crop. Preferably, temperatures should be recorded every day.

Figure 7 Low cost thermometer



Alternatively there are a range of digital thermometers on the market, these cost approximately £135-250 depending on whether they also measure relative humidity, plus £29-55 for each extra sensor depending on the length of the sensor lead.

2.3.9. Indoor ambient air cooled storage

These are above ground insulated structures which are cooled by the circulation of cooler outside air. Temperature control of these types of stores is achieved by convectional or mechanical ventilation (see Figure 8) through bottom inlet and top outlet vents that are fitted with dampers. Air can be humidified, if required. Ambient air cooled stores are relatively cheap to construct and operate, suitable for most hard vegetables which are harvested in late autumn and require storage until late March or April. Advantages and disadvantages are listed in Table 4.

Table 4 Advantages and disadvantages of ambient air cooled stores

Advantages	Disadvantages
• Cools as well as stores produce. • Relatively cheap to run due to low power requirement. • Lowest capital cost for mechanical cooling equipment.	• Dependent on ambient or outside air for inside storage conditions. • Limited storage period • Slow cooling

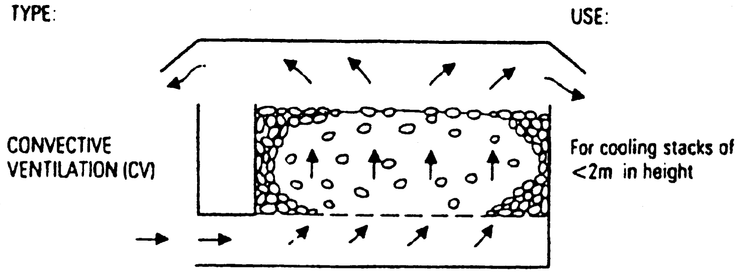
These stores are still widely used for conventional potato storage especially those destined for processing where higher storage temperatures are required to avoid the accumulation of sugars and chilling injury (Wills *et al.,* 1989). However, their use for organic potatoes is limited because sprout suppressants, not permitted by the organic standards, need to be used for long term ambient air cooled storage (Dent, 1988).

An ambient air cooled store ideally consists of:

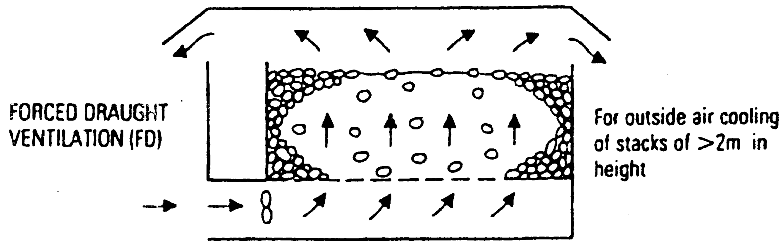
- air ducting for even air distribution and temperature control
- a suitable sized fan for use when ambient temperatures are low. These can be used with air mixing facilities to allow air recirculation and therefore control of cooling air temperature.
- some form of controls to monitor and regulate store temperatures.
- insulation to maintain store temperature as outside temperatures rise. This in turn will lower running costs and enables storage further into the spring.

Figure 8 Methods of mechanical ventilation

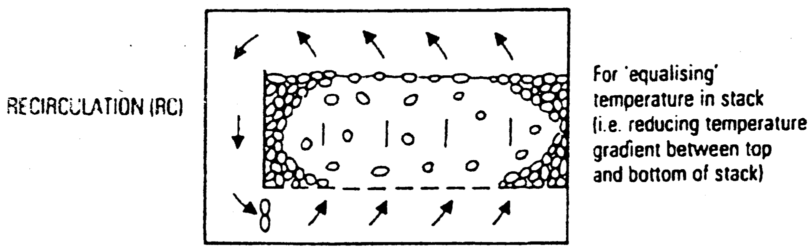
Convection Ventilation: Ventilation is achieved by natural airflow through openings in the structure of the store. Usually used in simple less expensive stores where short term storage is required.



Forced Drought Ventilation: Fans can be used as a means of forced aeration. This makes greater use of ambient conditions. Store size can be larger than for convectional ventilated stores. Fans can be automatically controlled using differential thermostats ensuring that ventilation only takes place when conditions are suitable (i.e. when outside air is colder than store air and above freezing). Ducts are required.



Recirculation: Can help control condensation by reducing temperature gradients. Existing store air can also be mixed with ambient air, useful when outside air temperature is lower than would usually be acceptable.



2.3.10. Constructing an ambient air cooled store

2.3.10.1. A large purpose built store

The price for a new building designed for bulk storage of 800 tonnes of potatoes is considered in section 2.5, Case Study 9.

2.3.10.2. Converting a building

Conversion is often less expensive than erecting a new building and may be better for reasons of siting and convenience. When to adapt an existing building and when to construct new is a question that can only be answered after all the circumstances have been considered.

If the decision is made to convert a building the insulation could be provided by various materials ranging from straw bales and polythene to insulation boards or panels. Storage temperature could be controlled automatically by fans that blow cold air through underground or surface ventilation ducts with the resulting warm air being expelled through louvers or doors to outside.

A case study (section 2.5, Case Study 7) is based on modifying an existing farm building (13.6m x 7.4m) at the Scottish Agricultural Colleges (SAC) to produce a store suitable for 100 tonnes of organic potatoes in boxes; insulating with Styrofoam, and installing a positive ventilation system, louvres, on floor ducts and an electrical control system. The total cost was £9,255.

Burton (1948) describes another example of a modified building. A shed, modified to suit local conditions that could provide a grower with potato storage. For organic growers this could provide a store for seed potatoes. Ware potatoes require a lower temperature for long term storage or sprouting will occur. Conditions inside the store can be expected to be:

- Constant 7-8°C or as low as 5°C.
- A dark ventilated store with rapid air movement.
- A moderately humid atmosphere of about 85% relative humidity.

The shed which has proved useful in the past in the seed potato growing areas of north Scotland (Keith, 1941) was 30.5m by 13.5m of 19mm wooden boards 2.1m high, on a cement base 1.1m high and 0.23m thick. The joints between the boards were covered with 19mm by 75mm laps. The roof was corrugated iron lined with felt and 12.5mm wood. Sliding doors (3.05m) high and wide were used at each end. These ran in a 75mm groove to prevent serious draughts. The mature maincrop could be stored in the shed to a depth of 1.5m, but this depth can be exceeded without damaging the tubers. In cold weather the shed was heated by coke braziers or paraffin stoves.

2.3.11. Refrigerated cool stores

Various fungicides are applied to conventional vegetables during crop growth or else after harvest to control diseases which develop in storage. At the start of this study there were some doubts as to whether refrigerated storage would be as effective for organic produce because pesticides are not used. However, pesticides are usually applied as a matter of precaution and are not usually so effective that they completely prevent losses due to disease.

Except for crops which suffer chilling injury the theoretical optimum temperature for cool storage for most crops is just above their freezing point. In practice most refrigeration equipment can run satisfactorily and reasonably economically at 0-2ºC. Relatively few diseases thrive at these temperatures. Humidity should be kept high to limit water loss and shrivelling, for many crops 100% humidity is the optimum. Although many fungi and bacteria are renowned for thriving in high humidities, paradoxically these conditions also keep the crop turgid making it hard for many rot causing fungi and bacteria to infect. Most storage rots are caused by weak pathogens that normally live as saphrophytes in the soil and can only enter the crop through wounds, through cells that have lost their turgidity or where free water is on the crop surface. As long as free water and condensation are not allowed to collect on the crop, the higher the humidity the lower the losses due to pests and disease. In practice relative humidities of 95-98% are aimed at during refrigerated storage. At 100% it can be hard to prevent condensation forming (see section 2.4 for each crop and the storage diseases, and section 2.3.12, Table 5 for optimum temperatures and humidities for storage).

Consequently optimum conditions required for organic crops are likely to be the same as those that have already been set and widely put into use for conventional crops. Organic growers already using refrigerated storage adopt the same conditions recommended for conventional storage with success. Inevitably, there may on occasions be higher storage losses than for conventional crops. In terms of crop quality the refrigerated method currently provides the best option for long term storage (beyond March) for most organic crops.

A few organic growers are also investing in small refrigerated stores for very short term storage. Often the crop is cooled rapidly and then stored for only a few days awaiting distribution and a mixture of crops are stored together. Since these stores are opened frequently, temperature and humidity tend to fluctuate and it is not advisable to attempt long term storage within the same store.

2.3.12. Optimum temperatures, humidity and expected storage life in cool storage.

There are many published recommendations for optimum temperatures, humidities and the expected storage life of particular crops. Unfortunately, there are considerable variations in the information given by different authors, especially when it comes to the expected storage life. Some variations can be explained because the experimenter ended the trial before the crop was exposed to warmer temperatures during marketing. Some storage disorders such as chilling injury do not become apparent until on the shop shelf. Other factors such as damage during harvesting, the temperature of the crop at harvest, pest and disease levels, characteristics of the soil in which the crop was grown, maturity of the crop at harvest and variety are all known to affect storage life. There are also different perceptions of what is acceptable quality. This in turn affects judgements on maximum length of storage. It is, therefore only realistic to provide guidelines for growers to experiment with and adapt to their own situation.

Ideally, crops should be stored just above their freezing point. Most crops freeze just below the freezing point of water at around -2 to -1ºC. The exact temperature can vary between cultivars and growing conditions as it is determined by the amount of soluble solids dissolved in the cell sap. In practice temperatures of 0ºC or just above give optimum storage conditions. However, there are some crops which show chilling injury well above the freezing point of their tissue.

Crops which are susceptible to chilling injury often originate from tropical or warmer climates e.g. avocado, courgette, pumpkin, cucumber, tomato, sweet peppers, aubergine, green bean, maize and citrus fruits. Symptoms include, pitting of the skin, brown spots, failure to ripen, water soaked appearance of the flesh, decline in flavour, loss of firmness and brown vascular tissue or stringy appearance in the flesh. It is important that temperature conditions in a store are monitored. The symptoms may not become apparent until the crop comes out of storage and is exposed to warmer temperatures on the shop shelf or with the consumer. Determining the temperature at which chilling injury occurs is not straightforward. The length of time a crop is at a particular temperature also affects the extent of injury. Usually the lower the temperature the faster chilling injury becomes apparent. Other factors which affect chilling injury are variety, maturity of the crop, temperature of the crop going into store and levels of gases such as oxygen, carbon dioxide and ethylene in the store.

One of the most comprehensive studies to obtain information on the optimum conditions for storage and the expected storage life was carried out by Robinson *et al.* (1975). It was found that a temperature of 0ºC and a relative humidity of 100% was optimum for a wide range of crops. It was reasoned that in practice temperatures of 1 to 2ºC and relative humidities over 95% were achievable with refrigerated cool stores available at the time. FarmElectric have more recently published temperature and humidity requirements for a range of cool stored crops and Thompson (1996) recently summarized the literature for a wide range of crops. Tables 5 and 9 are a compilation of this work, Robinson *et al.* (1975), FarmElectric (a) and Wills *et al.* (1989). Optimum temperatures and humidities are given together with the expected storage life of the crop under these conditions. In most cases more recent publications give shorter expected storage life than those found by Robins *et al.* (1975), probably because quality requirements of today's markets have increased. The table should only be used as an approximate guide; many factors affect storage life. By taking careful records of the conditions in the store and the quality of the produce leaving the store, a grower will gain experience of what to expect under their particular circumstances.

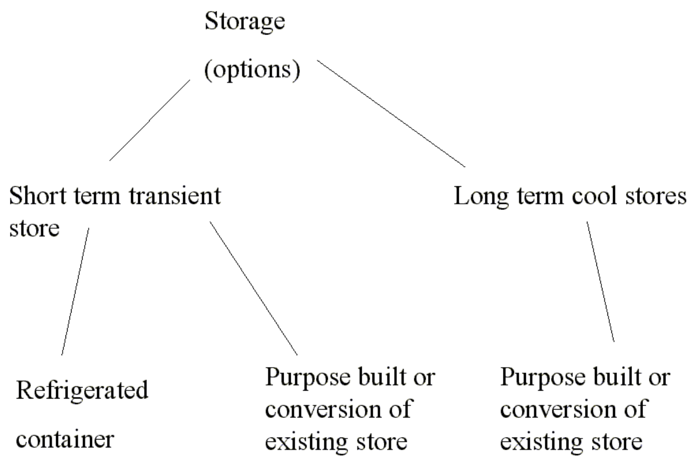
Table 5 Approximate guidelines for optimum storage temperatures, relative humidities, and maximum expected storage life under these conditions (long term storage)

Crop	Optimum		Maximum expected storage life (weeks)
	Temperature (°C)	Relative humidity	
Beetroot	3	95-98	12-20
Winter white cabbage	0	95	10-25
Carrot (mature)	0 to 1	95-98	12-20
Onions (bulb)	0	70-80	12-28
Parsnip (RH important)	0 to 2	>95	12-20
Potato (mature ware)	4-5	90-95	16-24 (at 5-9ºC)
Pumpkin	-	-	12-24 at (10ºC)
Swede	0.5	97-98	34-38
Turnip	0 to 2	>95	

Types of refrigerated storage

Although short term storage is outside the remit of this MAFF study, many organic growers requested information on this type of storage so it has been included in this section.

Figure 9 Refrigerated storage



A refrigerated store is, in effect, a thermally insulated box, with doors for entry and a means to cool the interior. Refrigeration secures correct store temperatures regardless of outside weather conditions. This permits long term crop storage through spring and into the summer months. Alternatively refrigerated cool storage allows rapid cooling times which is important with perishable crops, in transient or short term stores. The use of refrigeration enables the concept of complete crop cooling from the field through to the chilled retail shelf.

Field -------> Fridge store -------> Refrigerated transport -------> Supermarket chilled shelf

Cool stores for fruit and vegetables usually need to have a high cooling capacity, a close control of temperature with a variation of +/- one degree and a relative humidity of over 95% (Thompson, 1996). Long term storage requires low airflow systems to avoid dehydration.

2.3.13.1 Cooling systems

Crops have to be cooled and brought down to the required storage temperature when they first go into store. For some conventional crops such as potatoes and onions, forced ambient ventilation can be used to cool the crop and for the first few months of storage until March. Refrigeration can then be applied to complete the process until June or July. This reduces running costs by ensuring that the refrigeration unit is only run when required. This is only possible when ambient conditions approach desired storage conditions (Brice *et al.*, 1997). However, for organic potatoes and onions, because sprout suppressants are not used, it is safer to use refrigerated storage from the start.

Other crops require much more rapid cooling, various systems can be employed, advantages and disadvantages are listed in Table 6. Suitable systems for cooling various crops are given in Table 7. Conventional refrigeration with humidification is likely to be the most practical for organic growers. Moist air cooling with or without positive ventilation is most likely to be of use. These methods can also be used during storage. Hydrocooling and vacuum cooling are unlikely to be financially feasible for individual growers, they are more applicable to packers or large co-operatives. Likewise, controlled atmosphere as a means of cooling is expensive and is not suitable for cooling different crops together nor can the store be repeatedly opened and resealed.

Ice bank coolers use the cooling energy stored as ice during periods when the compressor has over-capacity and offers up to a fourfold increase in cooling capacity when compared to compressor only operation. Some of these systems are mobile and can be moved to wherever cooling is required. Ice bank cooling can be used to store calabrese and particularly parsnips preventing drying out and root discoloration. Ice banks are not commonly used commercially (Rickard,1996, pers. comm.).

Table 6 Cooling systems; advantages and disadvantages

Cooling system	Advantages	Disadvantages
Conventional refrigeration: Or direct refrigeration cooling	Adequate for long term storage. Relatively cheap to run, Relatively low power requirements, cheapest capital cost of the refrigeration systems.	Where a risk of weight loss to crops through desiccation exists, produce needs to be covered with plastic or humidifying systems may be required. Slow cooling up to 24 hours for vegetables, produce can freeze, requires skilled operator.
Moist air cooling: The basic refrigeration components as for conventional systems but cooling air is passed through a chilled cascade of water.	The humidified air can give crop cooling with minimal dehydration and, therefore, weight loss, moderately fast cooling (10-17 hours for vegetables), suitable for bulk produce, medium capital cost.	Not easy to use with packaged produce and difficult to chill different sized packages, high grade packaging material is required, skilled operator needed.
Hydrocooling: The crop is placed in a cold water bath or shower before storage	Fast cooling, no weight loss, crop cannot freeze, is a continuous process and can be included into washing, grading and packing lines. Good for carrots and parsnips which are washed anyway, can cool from 35 to 3°C in a short time (Rickard, 1996)	Product wet, waste disposal of effluent, holding store required, may need special containers, product may need drying, can spread disease, needs to be worked hard to justify high capital cost.
Vacuum cooling: A batch of crop is placed into a sealed container and the air removed lowering the air pressure causing water to boil. Heat is captured from the surrounding material in the energy change to vapour thereby cooling the crop.	Fast cooling, product can be cooled in package, simple operation, suitable for less dense leafier crops. Really only used for lettuce (Rickard, 1996, pers. comm.)	Weight loss about 1% for every 5°C drop in temperature, processing in batches, high power usage, produce can freeze, holding store needed, needs to be worked hard to justify high capital cost. Unsuitable for bulky crops or those with waxy coatings
Controlled Atmosphere Storage: Works by controlling the levels of oxygen and carbon dioxide in the store. Limiting oxygen levels slows down the respiration and, therefore, ageing process.	Can guarantee long term quality for crops such as apples, pears, cabbages which refrigeration alone cannot.	Crop stored must be high value to justify high capital and running costs, buildings usually have to be gas sealed although nitrogen flushing can be used if not. Store must be flushed out before personnel can enter unless own oxygen supply used.

(Adapted from ADAS, 1984d).

Table 7 Suitable systems for cooling various produce.
(Guidelines are based on research or commercial practice).

	Hydrocooling	Vacuum cooling	Conventional cool store	Moist air cooling
Outdoor vegetables				
Asparagus	+++	+	++	++
Beans - Green	++	+	+	+++
Brussels sprouts	+	++	+	+++
Beetroot	++	*	+	+++
Cabbage - Leaf	+	+++	+	+++
Cabbage - Head	*	*	++	+++
Calabrese	+	++	+	+++
Carrots	+++	*	+	++
Cauliflower	+	+	+	+++
Celery	++	+++	+	++
Chinese Cabbage	*	++	+	+++
Courgettes And Marrows	*	*	++	+++
Leeks	+++	+	++	+++
Lettuce - Butterhead & Crisp	*	+++	+	++
Onions - Dry Bulb	*	*	+++	*
Onions -Salad	+++	++	+	++
Parsnips	+++	*	+	++
Peas - Pod	++	+	+	+++
Potatoes - New	*	*	++	+++
Radish	+++	*	+	+
Rhubarb	*	+	+	+++
Sweetcorn	+	++	+	+++
Watercress	+++	+	*	+
Protected crops				
Celery	*	+++	+	++
Chinese cabbage	*	++	+	+++
Cress	*	+++	++	+++
Cucumbers	+	*	++	+++
Lettuce - Butterhead & Crisp	*	+++	+	++
Sweet peppers	*	*	++	+++
Tomatoes	+++	*	++	++
			(ADAS, 1984)	

(FarmElectric, 1997)
+++ Most suitable, ++ Suitable, + Less suitable, * Generally unsuitable

2.3.13.2.Humidifying systems

Good humidity control is vital as well as temperature control. Ambient air cooling and conventional refrigeration systems tend to dehumidify produce in store which can result in desiccation, weight loss and degrading of product quality. Pad humidifiers and moist air cooling systems (see cooling systems, section 2.3.13.1) are likely to provide the best solutions for organic crop as they are less likely to deposit water on the crop. See Table 8 for advantages and disadvantages of various humidifying systems.

Table 8 Humidifying systems

Examples of humidifying systems	Advantages	Disadvantages
Spray humidifiers: A relatively simple method that spays a fog of tiny water droplets into the airstream.	Lower capital and maintenance costs.	Control of the system can be problematic with moisture droplets being carried into the store onto the crop and building structure or too little humidity.
Pad humidifiers: Air is blown by a fan through a saturated pad of material.	System can be operated continuously without water droplet carry-over and crop wetting.	No information available.
Freezing fog: A fine water droplet spray is introduced into the store which is then frozen using chilled air at about -1 °C which freezes the droplets.	Longer storage periods can be achieved with crops such as; carrots, sprouts etc.	Light crop wetting can occur. Wetting and the low temperatures necessary can limit the number of suitable crops.

(FarmElectric, 1997)

2.3.13.3. Short term or transient storage

This enables produce to be held anything from four hours to two weeks and is mainly used for leafy vegetables, salad crops, strawberries (and perhaps even carrots in the winter). The store is used to rapidly take field heat out of the crop and thereafter remove heating caused by respiration. Cold, humid air is forced through pallets of produce.

Advantages of the transient store:

- Evens out peaks and troughs of supply and demand.
- Field heat can be removed quickly.
- Quality of product to customer is improved.
- Harvesting labour can be used more efficiently e.g. two or three days worth of produce can be harvested at once, reducing the need for weekend labour. Produce that is harvested on Friday can leave the farm on Sunday.

Humidity is high in a transient store, so good quality packing that can withstand the humidity levels may be required. The packaging needs to be perforated to allow cool air to pass through and ventilate the produce. If packaging is not necessary then use field crates. Ease of loading and unloading is facilitated by having uniformly sized pallets. (financial information is included in section 2.5, Case Study 6).

1) Refrigerated lorry backs and shipping containers

Second hand lorry backs and shipping containers are commonly used to keep produce cool, and their relatively low price makes them attractive to small scale organic growers. They are available in a variety of sizes from 3-12m long. (For more details on the cost see section 2.5, Case Study 5). Savings can be made by buying second hand containers but care should be taken to obtain a guarantee for any cooling equipment as this often goes wrong.

These containers are useful for short term or transient storage of relatively small quantities of produce (5-15 pallets depending on the size of the container) They do not usually contain humidifiers, small producers cover produce in wet newspaper to prevent it drying out. They are basically designed to keep produce cool and are unlikely to be effective at cooling harvested vegetables very quickly.

2) Small purpose built store

These can be a variety of sizes to suit the volume of produce required. They start as small as a prefab building which would contain a high humidity cooling system. A store equivalent in size to a 6m container would cost £4,500 (Horticold, 1997). This system is also suitable for long term storage.

3) Converting a building to a small cold store: a growers experience

A transient or small refrigerated store can be installed into an existing building. A relatively large scale organic grower on 161 acres running a box scheme as well as supplying supermarket packers adopted this approach. The farm grows vegetables, herbs, soft fruit, potatoes, glasshouse crops and has some land down to forage.

Details of the building are as follows:

Dimensions	6m (wide) x 12m (long) x 3.5m (high)
Capacity	1.5 days of sales
Crops stored	Mainly leafy vegetables, lettuce, calabrese, spinach, cabbage etc.
Duration of storage	4 hours to 2 weeks
Humidity	96%
Size of cooler	20kV
Cool down time	20 to 4ºC in 4 hours
Holding temperature	4ºC
Air flow	High
Insulation	Panels

The store can hold up to fifty 1m x 1.2m pallets but in practice usually only holds a maximum of 30 pallets. Any more than this and moving goods around becomes impractical. Since the farmer operates a box scheme he tends to enter the store frequently for small amounts of produce. If this is the case it a good idea to get a plastic door curtain. Try to reduce the number of times the store is entered as the cooler has to work very hard every time the door is opened which adds to the running costs (£4,000 on electricity alone, see Section 2.5 Case Study 6 for other costs). Produce should be harvested early in the morning, before 10 a.m. otherwise the produce is warm and the store is given more work to do. If air temperatures rise above 10-12°C while the crop is being harvested the store does not cope well and if the crop's respiration rate is high it can actually cook in the store instead of being cooled.

2.3.13.4. Long term storage

To optimise the storage life of fresh vegetables, close control of temperature and humidity is essential in order to store until April-June. This does require considerable expertise. As with short term stores, long term stores can either be purpose built or a building can be adapted. It is not recommended that the same store is used for short term storage as well as long term storage, since opening and closing of doors can prevent stabilisation of conditions.

1) Converting an existing building to a larger cool store: A growers experience.

The grower mentioned in 2.3.13.3 (3) also adapted a building for a long term store, suitable for boxes of produce (see section 2.5, Case Study 8 for full costs).

Details of the building are as follows:

Dimensions	13m wide x 30m long x 4m high
Capacity	300-400 one tonne boxes
Crops stored	Potatoes, onions, carrots
Duration of storage	1-8 months
Humidity	95% (ideally)
Air flow	Low
Cooler	20 kV
Store holding temperature	3-4°C
Insulation	Walls - 5cm spray foam, Roof - 7.5cm spray foam

The store is used from October to June. The different crops are stored together with reasonable success. A compromise on the storage conditions has to be reached, essentially conditions suitable for the storage of potatoes are used. Carrots are stored for two months in 1 tonne boxes. The humidity is a bit low and the temperature a bit high for long term storage. Onions, despite the high humidity, are kept from October until May.

For both long term and short term stores it is essential to lay a good floor so that a pallet truck can move around easily. It is advisable to buy new refrigeration equipment as second hand tends to break down. Whatever kind of equipment used make sure it comes with a warranty or a good guarantee. Savings can be made more safely by buying second hand boxes.

2) Posi-igloo system

This is a relatively new low cost method developed by the SAC for small scale refrigerated storage of seed potatoes within an existing building. The produce is placed in tightly stacked boxes within a moveable frame over which an insulated tent is positioned. When not in use the tent and frame can be stored. Many different crops can be stored/cooled with this method (Farm Electric, 1994) For a 64 tonne unit annual costs are approximately £26/tonne (Welvent, 1997).

2.3.14. Storing different crops together in refrigerated storage.

Since organic growers produce a wide range of crops it is likely that if they invest in cool storage they will wish to store several crops together. It is inadvisable to use the same store for long term storage as well as short term storage. If the store is opened frequently, not only will this incur substantial running costs but there will be temperature and humidity fluctuations which will affect the storage life of the crop especially those in long term storage.

2.3.14.1. Short term or transient storage

There should be no problems storing different crops together. This has been common practice for conventional crops in transit (MAFF, 1979). Although the main remit of the present review was to provide information on long term storage, some organic growers are contemplating the use of transient cool storage, so information for the storage of a wide range of crops which can only be stored for a short period of time is provided in this section (see Table 9).

The following guidelines should be observed when storing different crops together in transient cool storage:

1) The store temperature should be set so that produce requiring the highest temperature will not be damaged. For example if crops such as runner beans or courgettes, which are susceptible to chilling injury are to be stored with lettuce, Brussels sprouts etc. then a store temperature of 7-8°C will need to be selected and it will have to be accepted that the storage life of the other crops will be reduced. If none of the crops are prone to chilling injury then a store temperature as close to 0-2°C is usually best. In practice many transient stores run at 3-4°C because of the extra cost involved in bringing a store down below this temperature. Potatoes actually store better at this temperature; the lower the temperature the more sweetening occurs.

2) Products with a powerful aroma should be stored separately or they can taint other less strongly flavoured crops. e.g. onions can taint celery.

Do not mix group A with group B

Group A	Group B
Apples & pears	Celery, cabbage, carrots, potatoes, onions
Celery	Onions

(Coleman, 1989)

3) Crops which produce large amounts of ethylene as they ripen should be stored separately. Ethylene speeds up maturation and subsequently induces cell death and decay. Some fungal storage rots also produce ethylene thereby speeding up the decay process.

Do not mix group A with group B

Group A	**Group B**
Apples, pears, peaches, plums, cantaloupes, tomatoes	Lettuce, carrots, greens

(Coleman, 1989)

4) Humidity should be set to meet the requirements of crops which have a high optimum humidity. In most cases a humidity of 95-98% should prove satisfactory. Usually crops with lower optimum humidity requirements are simply more tolerant of lower humidities and do not suffer loss of turgidity. At lower humidities storage rots are less likely to develop in these crops, but if a high humidity requiring crop is placed in lower humidity, not only will it shrivel but the loss of turgor will make it very prone to storage rots.

5) The store should be entered as few times as possible. Produce entering the store should be as cool as possible. i.e. harvest in the cool of the morning.

Table 9 gives the optimum temperature and humidity requirements of a range of crops and (where information was available), their expected maximum storage life at 0°C, 2°C, 4°C, 8°C. These are store running temperatures which are likely to be practiced by growers storing a range of crops together. Finally, expected storage life at 20°C is shown where possible, this gives an approximation of the expected storage life under warm summer conditions.

2.3.14.2. Long term storage of different crops together.

There is less experience and information available than for transient storage. Ideally different crops should not be stored together because even if the crops have similar temperature and humidity requirements, their respiration rates, heat production, specific heat and ethylene production can differ and adversely affect each others storage life. Having said this, it is possible to store some of the more common long term stored crops together and this is practiced by some growers (Watson, 1996, pers. comm.). See also section 2.5 Case Study 8. It has to be accepted that a compromise needs to be reached on the storage regime and that maximum storage life probably won't be achieved. Table 9 gives an idea of expected storage life at sub-optimum as well as optimum conditions for a wide range of crops.

Table 9 Guide to maximum expected storage life of a range of crops.

Crop	Chilling injury (ºC)+	Optimum		St life*	Storage temperature (ºC)										
		Temp (ºC)	RH (%)		0		2		4		8		20		
					RH (%)	St life*	RH (%)	St life*	RH (%)	St life*	RH (%)	St life*	RH (%)	St life*	
Amaranth		0	95-100	1.5-2	95-100	10-14d	-	-	-	-	-	-	-	-	
Asparagus		0-2	95	2-4	95-100	1-4	90-95	2-3	>95	1-2	-	4d	-	1d	Spears may be stored overnight with butts in water
Aubergine	7	8-12	90-95	1-2	n/a	n/a	n/a	n/a	n/a	n/a	90-95	1-2	60	3-4d	
Avocado	4-11	5-9	85-90	3-5	n/a	n/a	n/a	n/a	n/a	n/a	-	1-2	60	2-7d	Some varieties need storing at 12ºC
Bean: green		4-7	>95	1-3	n/a	n/a	n/a	n/a	n/a	n/a	-	-	-	-	
Beetroot		3	95-98	12-20	95-100	12-21	90-95	8-14	95-98	24	-	16	-	1	
Broccoli		0	>95	1-2	95-100	1-2	-	-	-	-	-	-	60	1-2d	
Black raddish		0	90-95	8-17	90-95	8-17	-	-	-	8	-	4	-	7d	
Broad bean		0-1	95-100	2-3	95-100	2-3	85-90	1.5-2	85-90	1.5-2	-	-	-	-	
Brussel sprouts		0	95-98	2-4	95-100	3-5	-	1	-	5d	-	3d	-	1d	
Cabbage: summer		0	95	3	90-95	3-6	-	-	-	-	-	-	-		
Cabbage: savoy		0	95	5	90-95	5	-	3	-	-	-	-	-	5d	
Cabbage: winter white		0	95	10-25	95-100	12-25	-	14	-	10	-	7	-	2-3	
Capiscum: sweet pepper	7	7-10	95-100	1-2	n/a	n/a	n/a	n/a	n/a	n/a	90-95	2	65	2d	
Carrot: bunched		0	95-100	2-3	95-100	1.5-3	-		-	-	-	-	-	-	
Carrot: mature		0 -1	95-98	12-20	95-100	14-21	-	14	-	-	-	7	-	1	
Carrot: immature		0 -1	95-100	4-6	95-100	4-6	-	-	-	-	-	-	-	-	

Crop	Chilling injury (ºC)+	Optimum		St life*	Storage temperature (ºC)										
		Temp (ºC)	RH (%)		0		2		4		8		20		
					RH (%)	St life*	RH (%)	St life*	RH (%)	St life*	RH (%)	St life*	RH (%)	St life*	
Calabrese		0 -2	>95	-	-	-	-	-	-	-	-	-	-	-	
Cauliflower		1	95-98	2-4	95-100	2-4	-	4	-	2.5	-	8d	-	2d	Can tolerate lower humidities 85-95
Celeriac		0	95-100	16-32	95-100	16-32	-	17	-	12	-	7	-	7d	
Celery	-0.3	0.5-1	95	2-10	90-95	2-4	-	1.5	-	-	-	4d	-	1d	Storage life very variable at 2-12 wks
Chard, Spinach beet		0	95-100	1.5-2	95-100	1.5-2	-	-	-	-	-	-	-	-	
Chicory/Endive		0 -1	95-100	2-4	95-100	2-3	-	-	-	1.5	-	5d	-	2d	
Chilli peppers	approx 7	7-10	90-95	1-3	n/a	n/a	n/a	n/a	n/a	n/a	-	1-3	60	2-3d	
Chinese artichoke		0	90-95	1-2	95	1-2	-	-	-	-	-	-	60	1-2d	
Chinese cabbage		0-1	95-100	4-8	95-100	4-8	-	-	-	2	-	10d	-	2d	
Chives		0-1	95-100	1-2	-	-	-	-	-	-	-	-	-	-	
Collards		0	90-95	1.5-2	-	-	-	-	-	-	-	-	-	-	
Coriander		0	90-95	1	90-95	1	-	-	-	-	-	-	-	-	
Courgette	4.4-7	8-10	90-95	1-2	n/a	n/a	n/a	n/a	n/a	n/a	90-95	1-2	60	3-5d	
Cucumber	7	8-11	90-95	1-2	n/a	n/a	n/a	n/a	n/a	n/a	90-95	1-2	-	-	
Endive		0-1	95-100	2-3	95-100	2-3	95-98	2-3	-	1	-	4d	-	1.5d	
Fennel		0-1	95	1-2	90-95	1-2	-	-	-	-	-	-	60	2-3d	
Garlic		0	70	24-32	70	24-32	-	-	-	-	-	-	60	3-4	Sprouts rapidly above 4.4ºC
Ginger (root)	probably 7-10	13	70	16-24	n/a	n/a	n/a	n/a	n/a	n/a	-	-	-	-	
Globe		0-1	95-	3-7	95	2-3	-	-	-	-	-	-	60	2-3d	Crates lined with perforated

Crop	Chilling injury (ºC)+	Optimum		St life*	Storage temperature (ºC)										
		Temp (ºC)	RH (%)		0		2		4		8		20		
					RH (%)	St life*	RH (%)	St life*	RH (%)	St life*	RH (%)	St life*	RH (%)	St life*	
artichoke			100												polythene recommended
Horseradish (root)		0	95-100	42-50	95-100	42-50	-	-	-	-	-	-	60	7-10d	Immature roots do not stone will
Jerusalem artichoke		0	90-95	8-21	90	12-2	-	-	-	-	-	-	60	1-2	
Kale		0-1	95	2-4	95-100	1.5-2	-	-	-	-	-	-	-	-	
Kohlrabi		0-1	95-100	2-4	95	2-4	-	-	-	-	-	-	-	-	
Leek		0-1	>95	4-12	90-95	4-8	-	-	90-95	2	90-95	8d	-	1-2d	
Lettuce: crisp		0-1	>95	1-4	90-95	1.5-2	-	9d	-	9d	-	6d	-	2d	
Lettuce: butterhead		0-1	>95	1-2	90-95	1-1.5	-	8d	-	6d	-	4d	-	2d	Crisps heads normally store longer than butterhead
Marrow	7-10	10	60-70	6-10	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	-	-	
Mint		0-1	95-100	2-4	-	-	-	-	-	-	-	-	-	-	
Mushroom		0-1	85-90	3-7d	85-90	3-7	-	5d	-	4d	-	3d	-	1d	
Onions: bulb		0	70-80	12-32	75-85	24	-	-	-	24	-	17	-	3	
Parsley		0-1	95-100	4-8	-	-	-	-	-	-	-	-	-	-	
Pak choi		0	95	1.5-2.5	95	1.5-2.5	-	-	-	-	-	-	60	2-3d	
Parsnip		0-2	>95	12-20	98-100	16-24	-	-	-	-	-	-	60	4-6d	
Pea: in pod		0-1	95-100	1-3	90-95	1-2	-	-	95-100	4d	-	-		1-2	
Potato: mature ware		4-5	90-95	16-24	n/a	n/a	n/a	n/a	90-95 95-98	16-36 34	90-95	8-20	-	3	
Potatoe:		4-5	90-95	3-8	n/a	n/a	n/a	n/a	90-95	3-8	-	-	-	-	

Crop	Chilling injury (ºC)+	Optimum		St life*	Storage temperature (ºC)										
		Temp (ºC)	RH (%)		0		2		4		8		20		
					RH (%)	St life*	RH (%)	St life*	RH (%)	St life*	RH (%)	St life*	RH (%)	St life*	
immature															
Pumpkin	10	10-13	60-70	8-20	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	-	-	Storage life very dependent on variety
Radish with tops		0	>95	3-5d	90-95	3-5	90-95	2-3d	90-95	2-3d	-	-	-	1d	
Radish: without tops		0	>95	1-4	90-95	1.5-2	90-95	7-10d	90-95	7-10d	-	7d	-	2d	
Rhubarb		0-2	>95	2-3	95-100	2-3	-	-	-	12d	-	8d	-	2d	
Salsify		0	95-100	8-14	90-95	8-16	-	-	-	-	-	-	-	-	
Spinach		0-2	>95	1-2	95-100	1-2	-	6d	-	-	-	3d	-	1d	
Spring onions		0	95-98	1-3	90-95	1-2	-	-	-	-	-	-	-	-	
Swede		0.5	97-98	16-38	95-100	16-24			-	-	-	-	-	2	
Sweet corn		0-2	>95	4-8d	90-95	4-6d	-	-	-	5d	-	2d	60	1-2d	
Tomato: mature green	7	8-10	85-90	1-4wk	n/a	n/a	n/a	n/a	n/a	n/a	85-90	1-3	-	-	
Tomato: mature red	7	7.5-8	85-90	1	n/a	n/a	n/a	n/a	n/a	n/a	-	-	-	-	Can be stored at 1-4ºC for 3 wks but need to be used quickly
Turnip		0-1	90-95	8-20	95-100	8-17	-	-	-	-	-	-	60	1	
Watercress		0-2	>95	up to 1wk	95-100	4-7d	-	-	-	-	-	-	-	-	
White radish		0	90-95	17	90-95	16	-	-	-	8	-	4	-	1	
Winter squash		10-13	60-70	8-24	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	-	-	Storage life very dependent on variety

+: temperature at which chilling injury occurs
*: in weeks except when written ‘d’ (meaning day)
St: abbreviation for Storage
RH: abbreviation for Relative Humidity

Box storage rather than bulk storage is really the only practical way of storing different crops together. Different crops can be placed in individual boxes and the conditions of each crop can be monitored. If rotting occurs in a particular box it can be removed from storage relatively easily before the rot spreads through the store. By careful planning and positioning of the boxes movements for loading and unloading of different vegetables and batches can be achieved. The gaps between the boxes should be 50-75mm to allow sufficient air circulation and room for manoeuvre in stacking. It is important that there should not be large variations in the spacing between boxes, especially while the produce is being cooled. If it is known in advance that the store will not be completely filled it is better to reduce the loading height in the store to make sure more of the floor area is covered. To a certain extent the problem of partially filled stores can be overcome by the use of plastic film sleeves to cover the sides and top of a cooled pallet (MAFF, 1979) but there is little information published on this matter.

The same basic principles apply as for short term storage of crops together.

If the store is run at 0°C and above 95% relative humidity, beetroot, winter white /red cabbage, carrots, parsnips, swedes, turnips and onions (care with tainting) can be stored together and their storage life should approach the maximum expected. Beetroot actually store best at temperatures of 3°C and relative humidity 95-100% but storing it at a lower temperature is not too detrimental as high humidity is thought to be the most important factor over these temperature ranges. Onions theoretically store best at lower humidities, they can tolerate low levels which helps prevent rots. However, at 0°C progress of onion rot is very slow even at high humidities. As long as the crop appears healthy going into store there should not be too much problem.

If potatoes are to be stored after they have been cured, the store temperature needs to be run at 3-4°C, this temperature suppresses sprouting but limits low temperature sweetening sufficiently for normal ware use. Despite the optimum humidity for potato storage being 90-95% it is best to raise the storage humidity to 95-98% if storing with carrots, parsnips, beetroot or swede. Onions will also store well under these conditions as 4°C will inhibit sprouting reasonably well until March. However, the storage life of winter cabbage and turnips will be quite noticeably reduced (to about 10 weeks) at these temperatures.

More information is required about storing crops together long term especially at sub-optimum temperatures such as 4ºC. In practice crops are often stored at this temperature but very little information is actually published. Development of wrapping pallets in plastic film to increase humidity, dividing stores up with plastic curtaining, and using insulated tent systems within a barn or cool store e.g. Posi-Igloo, would be useful.

2.3.15. Box storage versus bulk storage

With bulk storage the product is stored loose rather than in a rigid container. Boxes can be used in either ambient air cooled storage, refrigerated storage and even in clamps. Box storage facilitates easy handling and unloading from the store.

Due to the cost of the boxes; box storage is 50% more expensive than bulk storage (Statham, 1996) but some savings can be made on the structure of the store as the retaining walls do not need to be so strong.

Within the last decade most newly built stores have been designed to accommodate boxes. The change from bulk to box storage began due to the requirements of the supermarkets and their client packers (Statham, 1996).

Although box stores are more expensive than bulk stores they are more suitable for organic produce. If there is a problem with a storage disease it is more likely to be confined to particular boxes. Small quantities can be loaded and unloaded as required. The boxes can be labelled to comply with auditing systems required by the organic standards for storage and transport. Different crop species or different harvests of the same crop can be kept separate yet still housed in the same store. (See Table 10 for summary of advantages and disadvantages).

Table 10 Advantages and disadvantages of box and bulk stores

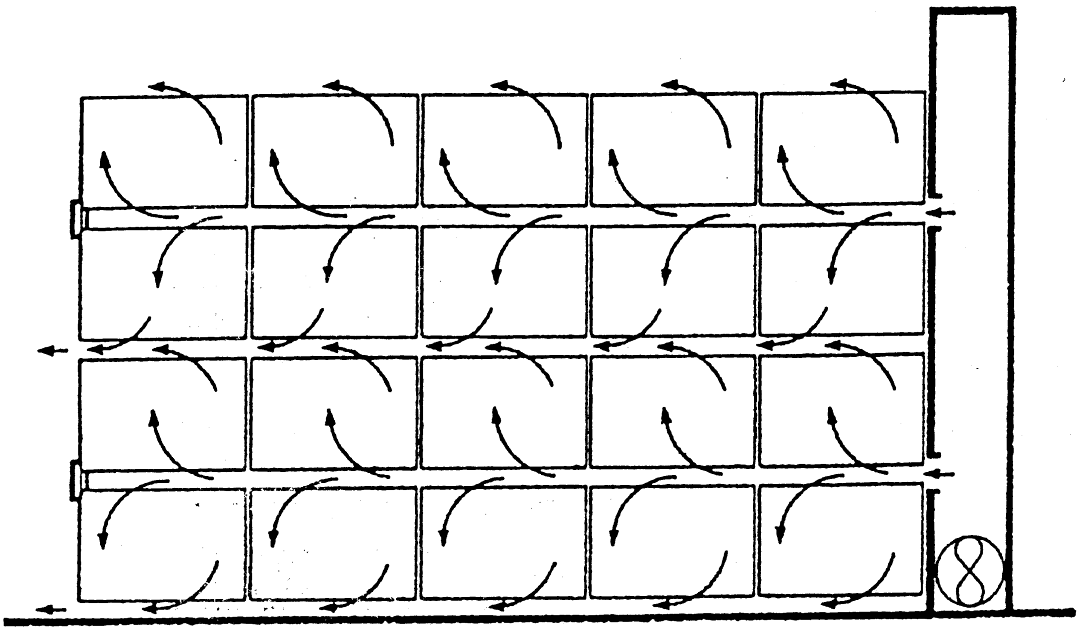
Box storage (advantages)	Box storage (disadvantages)
• Building design simpler as thrust walls are not required. • Variety and source segregation of produce simpler. • Reduced risk of disease spread as produce space separated. • Ease of outloading produce. • Maximum height of stored produce limited only by height of store.	• Capital costs 50% higher than bulk storage due to cost of boxes. • Difficulty in passing ventilation air through contents of boxes can cause slow response to control measures. • Hold less than bulk stores due to the store volume taken by the boxes and under-filled containers. • Boxes need regular repair • A forklift truck is required for the larger stores.

Bulk storage (advantages)	Bulk storage (disadvantages)
• Can also be used for grain storage. • Available store space can be used more efficiently. • Can suit a large scale mechanical harvesting and handling operation more, and require a lower labour input.	• Need for strengthened retaining walls when storing large quantities against walls. • As height of stacking in store grows temperature control becomes progressively more difficult. • Compression of crop can be a problem although artificial humidification can be used and has been shown to reduce the risk of compression damage in bulk stores • More complicated to separate different stored crops and varieties.

2.3.15.1. Ventilation systems for box stores

Cold air must be able to circulate around the stored produce and there is a debate as to whether air should be blown, sucked or diffused into a store. If a crop has a high respiration rate, a forced air system is required (Rickard, 1996). Most of the recently built box stores, the majority of which are refrigerated, use an air distribution system called 'Overhead Throw'. This is a low cost simple system that works very well at keeping temperature variations, even in multi-thousand tonne stores, below 2°C. Due to the space distribution system heat moisture and carbon dioxide have to leave the boxes by the slow processes of convection, conduction and radiation. Organisations such as the PMB have been looking into alternative positive ventilation systems such as the 'Letterbox Distribution System' (see Figure 10) and the 'Suction Wall Distribution System'. They give benefits in terms of reduced temperature gradients through a more rapid air exchange process, although there are extra costs involved.

Figure 10 Air flow in a letter box system



As ever higher quality standards are demanded the newer positive ventilation systems will assume greater importance in stores to be built in the future (Statham, 1996).

2.3.16. Insulation of stores

All buildings act as an 'insulator', but the term insulation is generally reserved for materials used in the construction of a building which have a specific property of resisting or opposing heat transfer. The amount of insulation and its life expectancy can markedly affect the running costs of a store. Some materials are clearly better insulators than others (e.g. timber as opposed to concrete or steel). Materials are measured according to commonly used criteria. The most frequently used of these is the 'U' value, a measure of the rate of heat flow expected through a structure under given temperature conditions. Better insulators are associated with lower values. Sometimes the 'R' value - for resistivity - is quoted. This is the inverse of the 'U' and as such gives larger numbers to represent greater insulating effect. Some examples of 'U' and 'R' values of common insulators of walls are given in Table 11.

Table 11 Insulation characteristics

	'U' value '(W/ ^{0}C m^2)	R' value (^{0}C m^2/W)
215mm dense, hollow concrete blockwork	2.05	(0.49)
215mm solid wall of foamed blockwork & rendered both sides.	0.45	(2.22)

(Bomford, 1995)

In storage buildings a variety of materials may be used to insulate ranging from straw through to insulation board or spray foam. These can be fitted into existing buildings to improve their insulation.

From a farmers point of view the best insulation is the cheapest that provides the required performance. Whichever material is used a vapour barrier has to be placed on the warm side of the insulation to stop moisture passing into and condensing within the insulating material (Wills *et al.*. 1989). Thermal insulation has to be kept dry (static dry air is the best insulation) to be effective. If the moisture content of glass fibre is raised by a little over 1% there is a 75% reduction in insulating capabilities.

The pattern of marketing and store clearance must be considered when designing the level of insulation for a store. The longer storage is required after February, the better the thermal insulation needs to be. It should not be thought that good insulation is only important for a refrigerated store. On the contrary, for ambient air cooled stores where ventilation with outside air is the only means of controlling store temperature, insulation in times of high ambient air temperature is as essential as ventilation.

Higher levels of insulation are required for refrigeration. Better insulation will lead to lower operating costs, as the table below shows. Table 12 compares three different levels of insulation for a store.

Table 12 Variation in Insulation levels (for refrigerated stores)

Level of insulation U Value	Electricity consumed kWh
0.25	24600
0.35	26600
0.45	29000

(Bishop, 1992)

2.3.17. Energy efficiency and power sources

More sophisticated storage systems use a power source such as electricity or a diesel engine to cool the produce. As mentioned in the section above a key to reducing running costs is to have good insulation. Other important aspects are:

- Regular maintenance of equipment to see that it operates optimally.

- Good control systems (e.g. thermometers) which are accurate.
- Check for draughts from badly fitting doors and gaps in the structure and minimise opening the store for loading/unloading.
- Use electricity when tariffs are cheaper (night time) e.g. this is exploited by ice banks.

2.3.17.1. Renewable power sources

The use of renewable energy sources such as wind and solar power is probably only financially justifiable on either a very large scale or on a very small scale where there is no existing electricity supply.

On a large scale, generating electricity by wind power only becomes viable when the generating capacity of the wind turbine exceeds 220kW and either all the electricity generated is used on site or excess is sold to the grid. This size of turbine would cost around £700-800 per kW installed, i.e. £160,000 including installation, and would be capable of supplying a large complex of stores. At present supplying the grid is not particularly favourable. For a normal contract the grid pays approximately 2.5p/unit. For a non-fossil fuel contract the grid pays approximately 4p/unit. The grid supplies businesses at around 6-7p/ unit. So any electricity used on site is worth more. The situation may become more profitable in the near future with the introduction of 'green electricity' where both business and household consumers can choose which companies supply them. It is hoped that green electricity will fetch 6-7p/unit for the grid supplier (Ellis, 1997, pers. comm.). Even if it is not viable to generate 'green electricity' oneself it is hoped that it will be supplied at competitive prices. Opting for this type of supply may be a viable option which fits in with the general ethos of organic farming which aims at creating a sustainable system.

At the other end of the scale it may be worthwhile considering a renewable energy system store in a location where there is no existing electricity supply. It usually costs in the region of £5,000 to connect to the grid. A combination of solar and wind power may become a viable option costing around £4,500 fully installed. For example, to power a 1-2 kW refrigeration unit for a small refrigerated lorry back 15-20ft x 8ft x 8ft. would require:

- 5x 75W solar power modules on roof (10-20 years life). Relatively maintenance free, just need to clean panels and check connections. (Approximately £1,800).
- Small wind charger, 75W, of the type often seen on boats. Maintenance, check every so often that it has not shaken itself apart, bushes usually need replacing every 2 years. Expected life around 10-20 years. (Approximately £500).
- Battery bank to store electricity on site. Maintenance needs checking every month unless more expensive maintenance free batteries used. Expected life, 5 years. (Approximately £500).
- Inverter to produce 800W at 240V. Changes electric current from direct to alternating, and 12V to 240V. Expected life 5-10 years (Approximately £700). Installation costs (Approximately £1,000).

Vortec Energy a New Zealand based company is working on a prototype wind turbine which may be as economic as other forms of energy. The idea of turbines using shrouds to produce a region of low pressure which sucks air past its blades at up to twice its normal speed is not new, but with the use of new light weight construction materials, this has made commercial construction a reality. The company says that they will be able to produce up to six times the energy of a conventional turbine at only three times the construction cost (Anderson, 1997).

Further sources of information on renewable technology are:

Renewable Energy Advice Centre. Tel: 01908 501908.

Energy Technology Support Unit. Tel: 01235 432450/433601.

British Wind Energy Association. Tel: 0171 402 7102.

Proven. Tel: 01563 543020.

Centre for Alternative Technology. Tel: 01654 703409

2.4. STORAGE OF SPECIFIC CROPS

2.4.1 Potatoes

2.4.1.1. Current practice and problems

Potato storage has been well researched and has been a major focus for the PMB. Consequently the technology for storing conventional potatoes is well developed. Many of these methods are also suitable for storing organic crops, and much of the knowledge available about optimum growing, and harvesting conditions to promote long storage life, is of relevance to the organic grower. Most potential storage problems can be avoided using good growing and harvest practices.

It is reasonably common for organic growers to store potatoes, either for a few months in clamps or up until March in ambient air cooled stores. A few growers use refrigerated storage.

The main technical problem for organic storage is the prevention of sprouting during long term storage. Without cool storage most varieties start to sprout by December. Conventional potatoes are often treated with chemical sprout suppressants so that they can be held at 7-8ºC. By lowering the store temperature to 3-4ºC most varieties for ware production can be stored without the use of sprout suppressants until May. Sprout suppressants do have some drawbacks for example chloropropham can actually delay healing during curing and lead to more skin spot and other storage diseases (Gunn, 1990 & Anon., 1990). With public concern over the safety of sprout suppressants some conventional stores are switching to storage below 4ºC.

Sprout prevention is more of a problem for potatoes destined for processing, especially crisping. Low temperature storage causes the accumulation of sugars in tubers resulting in unacceptably dark fry colour. As far as is known there are no organic crisp manufacturers in the UK, so this is not an immediate problem. There has been some work on the use of controlled atmosphere storage to suppress sprouting in conventional potatoes, but this work is still in its infancy and there is evidence that other aspects of quality may be adversely affected (Storey, 1996).

Storage at 3-4ºC inhibits most potato storage diseases. Gangrene (*Phoma exigua* var. *foveata*) and skin spot (*Polyscytalum pustulans*) are the most likely problems under these conditions. Some trials have shown that the application of fungicides to control these two diseases had no beneficial effects as long as the tubers had been cured and storage temperatures remained at 2.5º C (Anon., 1991).

If storage temperatures reach above 10ºC, which can be the case for some periods in clamps or during curing, diseases such as tuber blight (*Phytopthora infestans*) and bacterial soft rots (Erwinia spp.)are likely to be the most important in organic potatoes (Ginger & Aspinall, 1987).

Silver scurf (*Helminthosporium solani*), Dry rot (*Fusarium* spp) and watery wound rot (*Pythium ultimum*) can also develop. Black scurf (*Rhizoctonia solani*) and black leg (*Erwinia caratovora*) can also be a problem on organic seed potatoes.

2.4.1.2. Growing for storage

1) Choose appropriate varieties (see Table 13)

Characteristics to look for are:

- Varieties with long dormancy to avoid sprouting in store e.g. Pentland Javelin, Romano, Majestic. Some varieties will sprout more quickly than others once they leave cool storage and this must be taken into account during marketing e.g. Sante has this tendency (Anon., 1992).
- Early maturing varieties to ensure good skin and allow early lifting before soil temperatures drop or soils become too wet.
- Varieties with resistance to tuber blight as well as foliage blight are of primary importance followed by resistance to other storage diseases.
- If cool storage (at 3-4ºC) is intended, choose varieties with resistance to gangrene and skin spot.
- If the potatoes are intended for processing, choose varieties which are less susceptible to low temperature sweetening. e.g. Brodick, Saturna.

2) Avoid diseases (see Table 14)

There are a number of cultural measures which can help prevent storage diseases and skin blemish diseases in the first place. These include:

- Using long rotations e.g. eight years to avoid dry rot (4-5 years helps alleviate infection).
- Avoiding ground keepers, this is especially important for blight. Set the riddle when harvesting so the small tubers are lifted. Rogue out ground keepers which grow in following crops. Use careful autumn tillage to bring tubers to the surface where they can be killed off by the frost.
- Using resistant varieties.

Avoid seed borne storage diseases. Use high quality seed. Skin spot is primarily seed borne. Seed tests are available to assess the risk of blackleg (Cunnington, 1997)

Table 13 Characteristics which promote successful storage and some commonly used varieties

	Brodick	Cara	Desiree	Estima	Nadine	Pentland Javelin 1st Early	Record	Remara	Romano	Sante	Saturna	Saxon	Stirling	Wilja
Dormancy of seed potatoes	5	6	5	5	3	8	5		7	4	3	6	5	5
Foliage maturity	5	2	4	5	6	8	5		5	5	5	6	3	5
Damage to tubers	7	7	5	6	6	7	6		5	6	4	7	8	6
Bruising to tubers	7	8	5	7	8	7	5		8	8	4	8	6	5
Foliage blight	7	5	5	5	6	4	4		6	5	4	4	7	4
Tuber blight	7	7	4	5	4	2	5		5	6	5	4	7	5
Gangrene	6	5		5	7	5	5		4	3	-	8	5	5
Early yield	-	-	5	9	7	8	7		-	-	-	9	-	7
Total mature yield	8	8	7	7	7	6	7	(7)	7	7	5	7	(8)	7
Total marketable yield	-					-		(6)	-		-	-	(8)	(5)
Foliage blight	-	(7)	(4)	(5)	(4)	-	(2)	(6)	-	(5)	-	-	(8)	(2)
Tuber blight		(6)	(4)	(3)	(5)		(3)	(7)		(3)			(6)	(3)

Figures in ( ) are provisional data from organic trials (NIAB,1997a)

Glossary of characteristics:

- Dormancy of tubers: Dormancy is considered broken when 50% of seed tubers have sprouts greater than 3mm. Figures are derived from observations on common origin seed. 9 = long dormancy period.
- Foliage maturity: Figures are based on records of natural senescence in the field. 9 = early foliage maturity.
- Damage: A visible splitting of the skin caused by physical impact. Figures are based on frequency of damage in controlled laboratory tests. Tests do not incorporate the effects of tuber size, shape, uniformity or the retention of stolons at lifting. 9 = good resistance to splitting.
- Bruising: A grey or blue-black localised discoloration which develops in the tuber flesh as a result of physical impact. Surface damage may not be apparent. Figures are based on laboratory tests and encompass both the frequency and extent of bruising. 9 = low occurrence of bruising.
- Foliage and tuber blight: The major fungal disease of potatoes. Blight reduces yields and marketablilty, and may cause losses in store by encouraging soft rotting. Figures are based on laboratory tests and field exposure trials. 9 = high resistance.
- Gangrene: One of the principal causes of seed losses and tuber rots in store. Gangrene is encouraged by tuber damage and low temperatures (<4ºC). Figures are based on laboratory and riddle damage tests. 9 = high resistance.
- Early yield marketability: Yield from immature harvests, figures are given for first and second early varieties only. 9 = high early yield.
- Total mature yield: Marketable yield at or near maturity. 9 = high marketable yield.

Table 14 Potato diseases control strategy

Time/site	Factors	Stem Canker and Black Scurf	Blackleg and soft Rot	Blight	Sclerotinia	Verticillium Wilt	Common Scab	Powdery Scab	Watery Wound Scab	Pink Rot	Gangrene	Skin Spot	Dry Rot	Silver Scurf
Seed	Use of resistant cultivars		*	**			**	*			*	*	*	
	Avoidance of very susceptible cultivars		*	*			**	**			*	*	*	
	Use of healthy seed	**	*	*		*	*	**			**	**	*	**
	Sprouting of tubers	*		*			*				*	**	*	
Field and cultural	Careful disposal of diseased tubers			**				**	*	*				
	Sound rotation	*			*	*		*	*	*				
	Avoid planting too early	**												
	Avoid deep planting	*												
	Avoiding compacted/wet soils		*					*		**				
	Avoid over-liming/high pH soils						**							
	Appropriate irrigation		*	*			**	**						
Harvest	Harvest in warm dry conditions		*	*			*	*			*	*		*
	Avoid mechanical damage to tubers		*						*		**		**	
	Keep diseased tubers out of store		**	**						**				
	Appropriate storage regime		*	*							**	**	**	**
Use of fungicides	On growing crop			**										

** most effective
* some effect
(Gunn, 1990)

3) Promote early maturity.

Choose early maturing varieties: Pre-sprout (chit) as appropriate for the variety so that the seed is more physiological advanced at planting (this can be done in a light frost free area such as a polythene tunnel). Plant as early as possible but only when conditions are suitable. This all promotes early maturity and hence early harvest (Cunnington, 1997).

Avoid over feeding. This is not usually a problem in organic systems, but it may be possible if there are high inputs of manure. Excess nitrogen can delay maturity, leading to more damage at lifting and poor storage.

4) Avoid excess or erratic irrigation.

This can lead to increased foliage blight, splitting and damage of the tubers and reduced dry matter content. Crops with high dry matter content generally store better that those with low.

2.4.1.3. Harvesting for storage

1) Avoid late harvests

Harvesting in the cold and wet encourages disease transfer, tuber damage, and excessive soil sticking to the tubers. Crops which are harvested early generally store better. Harvesting in September and October greatly reduces losses in store, when harvested in the dry and tuber temperature is above 10°C they are less prone to damage and blight (Dent, 1988). Potatoes lifted from a cold wet soil are more susceptible to gangrene, skin spot and silver scurf, likely to sprout and are difficult to 'cure'. As a guideline, store loading should be completed by 20th October.

2) Harvest after the haulms have died down or been removed

Ideally harvest should be 2-3 weeks after the haulms have died down or have been defoliated. Not only does this allow skin set but 2-3 weeks should be long enough for any blight spores in the soil to have died off reducing the risk of contaminating the tubers during harvest. It is vital that the skins have set properly, tuber temperature should be between 10 and 15° C (PMB, 1996b). Skin set makes the tubers less prone to damage, moisture loss and discourages the entry of many storage diseases. However, if the skin setting period is more than 14 days the risk of infection with gangrene is increased. (Gunn, 1990)

3) Avoid lifting immature potatoes

Immature potatoes are more likely to 'skin' during harvest, have a high respiration rate and are therefore prone to overheating in bulk stores, softening (due to water loss) and compression (bruising).

4) Keep the tubers dry

Tubers which have been rained on must never go into store. Harvest on a dry day, the crop can then be left on the ground to dry for a few hours after lifting. This can make a big difference to the success of storage. On a dry day with a breeze the tubers can be dry within an hour. (Do not leave the potatoes out too long (i.e. more than 24hrs for mature tubers) or they will green, any immature potatoes will green within 2-3 hours).

5) Avoid damage at harvesting

Overhaul all harvesting and handling equipment well before harvest, especially components which may damage the tubers. Harvesters need to be adjusted properly. Get the correct forward speed, web speed and web agitation. Keep machinery well maintained. Potatoes should not be allowed to fall more than 12", cushion hard surfaces wherever possible and avoid rough surfaces on trailers, baskets and elevators.

2.4.1.4. Loading into store

During transit protect tubers from rain

Do not attempt to try to remove soil which is stuck to the tubers as excessive agitation causes damage and bruising. But remove any loose soil (with soil extractors), as this impedes ventilation and temperature control within a store leading to condensation problems and ultimately rots. When loading a bulk store, move the discharge point frequently so that soil cones are less likely to develop.

In bulk stores potato piles which are over 2m deep and have no underground ducting will need ventilation ducts laid through the pile as it is made.

2.4.1.5. Curing

Potatoes which are cool stored are normally 'cured' before the temperature of the store is brought down. Curing is done at temperatures between 10 and 15° C. Where temperatures in the store are at a minimum of 10° C curing should take about 3 weeks. At 12-15° C a minimum of 10 days is required. Temperatures below 10° C are not satisfactory. The curing process promotes wound healing, reducing the chances of softening and diseases gaining entry. At 15° C the respiration of the crop is high and relative humidity in the store soon reaches 95% which prevents moisture loss. However, at this humidity any diseases already present will spread rapidly through the store. For this reason curing of organic potatoes should take place for as short a time as possible.

Dry curing is also recommended. The crop should be ventilated when the humidity of the air outside is low but its temperature is high enough to maintain curing. Dry curing has been shown to be beneficial against skin spot and gangrene (Dent, 1988), silver scurf and bacterial soft rot (PMB, 1996b). The crop should be inspected daily during curing and at the first sign of any deterioration such as soft rot, curing should be stopped and the temperature brought down to 4° C as quickly as possible.

Where the store takes a long time to fill or it takes a long time to cool the crop (e.g. ambient air or refrigeration only) it may be a good idea to modify the length of the curing period to compensate for the time taken to bring down the whole of the store to the final storage temperature.

Usually where potatoes are to be clamp stored, curing equipment is not usually available. Ambient temperatures are usually still above 10ºC anyway, so slow curing will take place in the clamp.

2.4.1.6. Drying potatoes lifted from wet soil

It is not recommended that organic potatoes should be lifted from wet soil unless a dryer is available as they need intensive drying. Forced ventilation systems are effective. Drying must be done carefully as it tends to cool the tubers and excessive ventilation can lead to rapid dehydration, shrivelling and softening of the crop once the surface moisture is removed. Use the forced ventilation system at maximum airflow (i.e. up to 0.04 m^3/s/t). Stop as soon as the surface moisture is removed and then switch to dry curing.

2.4.1.7. Dealing with rained on crops

Tubers which have been rained on, lifted from waterlogged soil or show signs of disease such as blight, blackleg, pink rot and rubbery rot should not be stored. Healthy portions of the crop should be sold as soon as possible.

If temporary cool storage is available, dry the tubers and cool them straight away without curing (see drying potatoes lifted from wet soil). Bring the crop down to 4° C as quickly as possible and sell as soon as possible.

2.4.1.8. Once in store

Once cured and put into store the crop should be inspected weekly, if any problems develop the remaining sound crop should be sold straight away. Crop inspection is not usually practical in a traditional clamp.

2.4.1.9. Clamps

Clamp storage can be suitable up until December. Some growers successfully store for longer, but it then only becomes suitable for supplying box schemes, as most varieties will need desprouting (see section 2.3.7 for more information on clamps).

2.4.1.10. Ambient air cooled stores

Temperatures in ambient stores are not usually low enough to suppress sprouting beyond March/April. After this time, night temperatures regularly rise above 4ºC so the store cannot be cooled. Temperature can be monitored using general purpose thermometers buried in the pile and maximum - minimum thermometers above the pile (PMB, 1996b). If the stacks, in the case of potatoes, are less than 2m in height a fan is not necessary. All that is necessary is to open and close the ventilation ducts according to the outside temperature. Temperature control becomes more difficult as the size of the pile increases and fans are required. Temperature control can be made easier by storing in small containers (1 tonne downwards). During frost periods, the ducts and vents should be closed.

If the building is poorly insulated the pile should be covered with 0.5m of loose straw to absorb any dripping condensation. This becomes in effect an indoor clamp. If there is some roof insulation in the building straw may not be necessary. If the air above the stack drops below freezing, cover the top and sides of the stack with polythene or similar.

2.4.1.11. Refrigerated cool storage

Most varieties of potatoes will store without sprouting until April or May in cool storage at 3-4ºC and a relative humidity of 90-95%. However care has to be taken over the choice of varieties as some e.g. King Edwards, will still sprout at these temperatures and are therefore unsuitable for long term storage. At these sorts of temperatures most postharvest diseases can not develop but gangrene and a skin blemish disease, skin spot can still develop slowly. Curing can help prevent both these diseases.

2.4.1.12. Store unloading

Before the tubers come out of cool storage the store temperature should be raised to about 10° C. This makes the potatoes far less susceptible to damage and bruising while they are unloaded and distributed.

2.4.1.13. Some important storage diseases and how to avoid them.

Potato blight

Potato blight caused by *Phytophthora infestans* can be a serious problem in both conventional and organic crops. It is most prevalent in warm wet seasons, the summer of 1997 has been such a season, and there have been serious outbreaks of foliage blight in organic main crop potatoes.

The fungus overwinters in diseased tubers remaining from the previous year's crop either in volunteers or undetected in seed. These tubers then release spores which infect the foliage. If the foliage becomes infected it does not necessarily mean that the tubers will become infected. It is a common miss-conception that tuber blight is caused by the fungus growing down the stems and entering the tuber via the stolon.

The main sources of blight spores are from:

Airborne spores from outside the crop e.g. other crops, volunteers, discard heaps. (The risk of affecting tubers for storage is negligible from this source but it is the main source of foliage blight infections).

Airborne spores from the crops own canopy (ensure complete death of foliage before lifting).

Spores on the soil surface which infect the tubers as they are lifted - the numbers of living spores fall to negligible level after 14 days absence of green foliage.

Contamination from machinery. e.g. from blighted tubers going through lifting, loading machinery etc.
(Gunn, 1990)

Ideally foliage blight should be controlled using cultural techniques but Bordeaux mixture, copper sulphate and copper oxychloride foliar treatments are permitted under organic standards. The effectiveness of these chemicals is limited and they need to be applied before the blight spores arrive. Blight spores are likely to be produced in rainy conditions when there has been two consecutive days at 10°C or above and relative humidity is at least 90% for at least eleven hours each day. Even if spraying is reasonably successful it does not necessarily mean the tubers will not be affected. Prolonging the time the foliage is green can actually increase the chance of tuber blight because the infected leaves will sporulate for longer. Because the fungus needs living tissue to reproduce heavily infected haulms which die down at least a week before harvest are less of a risk for tuber blight (Walker, 1957).

There are a number of cultural strategies that can be used to avoid blight in storage:

The use of resistant varieties. Especially those which have tuber blight resistance, however, none are completely resistant (see Table 13).

Good ridging to ensure tubers are not exposed. Exposed tubers can be directly infected from spores splashed from the infected foliage. Good ridges with no cracking of soil reduce the risk of spores being washed down through the soil and they also help to shed rain.

Irrigation should cease as soon as foliage blight is detected. This helps to stop the spread of blight through the foliage, reduces humidity in the crop canopy and reduces the number of spores washing down through the soil.

At least 2 weeks should be allowed between haulm removal or complete death to allow spores in the soil to die so they can not contaminate tubers as they are lifted.

Early defoliation This can be useful in certain circumstances for susceptible varieties. Advice varies about when it is best to defoliate (anything from 5 to 25% leaf area affected. It is probably only worthwhile for susceptible varieties. Very resistant varieties are best left to bulk up as they are unlikely to lose more than 5% of their yield to tuber blight (Wastie *et al.*, 1993 and Hirst *et al.*, 1965). Desiccants for defoliation are not permitted under organic standards so the haulms need to be destroyed mechanically or by flame. In practice defoliation is usually only done by larger organic growers who have grown a susceptible variety and have access to appropriate machinery. A grass topper can be used or a haulm pulveriser. Thermal defoliation is expensive as a lot of material would have to be burnt off. Smaller growers do not usually defoliate they allow the foliage to die down naturally and wait at least 2 weeks until lifting. This appears to work well (Tolhurst, 1997, pers. comm.).

If the crop appears healthy at harvest, storage may be contemplated. Even if the tubers appear healthy they can still have mild infections which do not become apparent until in storage. ADAS offer a service (code 3026) costing approximately £60 + VAT which can determine the level of infection before or during the initial stages of storage.

A number of measures can be taken to avoid problems developing in store:

Avoid damaging the tubers at lifting and grading.

Grade out green tubers. These will have been at the soil surface and exposed to blight spores.

Cure with dry air before long term storage.

During curing check the potatoes daily. Affected tubers should be removed.

During storage check for blighted tubers every few days and remove them.

Tubers which have remained blight free until Christmas are unlikely to be infected and will probably remain healthy until spring (Mawson, 1997).

2.4.1.14. Gangrene

Gangrene is caused by the fungus *Phoma exigua* var. *foveata*. It is not usually seen on tubers until at least a month after harvest, usually much longer. It can be spread either from spores from the mother tuber or washed down through the soil from diseased haulms. The fungus can remain living on the haulms even after they have died off and this can be a source of infection as the tubers are lifted. The most common way the fungus enters the tubers is through wounds.

No varieties are fully resistant, but NIAB (1997a) give ratings for relative susceptibility. Early lifting of tubers when conditions are relatively warm results in less gangrene. Avoid damaging the tubers during lifting and grading. Curing will also help to reduce infection. Infected seed tubers are usually easy to detect at planting and should not be planted.

2.4.1.15. Potatoes for processing.

Without the use of sprout suppressing chemicals most varieties need temperatures between 3-4ºC for storage beyond December or sprouting will occur. Unfortunately, low temperatures cause the accumulation of reducing sugars in the tubers which when processed produce an unacceptably dark fry colour. Acceptable levels of reducing sugars for processing in the UK are currently <0.2% for crisping, <0.25% for chipping and <0.5% for dehydration (PMB, 1996b). Higher values are acceptable in other European countries especially for crisping. A possible short term solution to the problem is that either stored tubers are avoided for processing or crisp manufacturers accept a darker fry cover.

There are two types of sweetening:

'Low temperature' sweetening -This occurs in tubers stored at temperatures below 4° C. Some varieties are more prone to it than others. Brodick and Saturna are less prone than other varieties but as yet there are no varieties which are immune. Breeding programmes are in progress to try and produce better varieties. Low temperature sweetening can be reversed to some extent by reconditioning. At the end of storage the temperature is raised to 15-20°C for 2-3 weeks. Some varieties respond better than others and breeding programmes are in progress to find more responsive varieties.

'Old age' or 'senescent' sweetening - occurs where there are high storage temperatures and/or prolonged periods of storage. Some varieties are more prone than others and it can not be reversed by reconditioning.

2.4.2. Onions

2.4.2.1. Current practice and problems

The bulb onion (*Allium cepa*) is a biennial plant, growing vegetatively to produce a bulb in its first year, then it enters a period of dormancy and finally flowers in its second year. The length of dormancy depends upon the variety and the temperature at which it is stored. This natural tendency for dormancy is easily utilised during storage. On the whole storage of organic onions up until March is not considered a major problem. After a period of curing, onions can be stored relatively successfully using simple technology such as clamps, ambient air cooled barn storage or even just in a frost-free place in a barn or lean-to.

The main problem for organic storage is preventing sprouting and the break of dormancy during long term storage i.e. until May/June. External sprouting can be prevented using refrigerated storage but internal sprouts can start to develop in a significant proportion of the crop, especially if stored until July. Conventional onion crops are sprayed with maleic hydrazide about 1 month before harvest to reduce sprouting during cool storage. This chemical persists in the stored bulbs, and is not permitted for use in organic standards.

Controlled atmosphere storage is currently practiced in the UK and is proven to be successful at storing conventional onions until July without the use of sprout suppressants. It is likely that this would also be technically possible for organic onions, but the use of controlled atmosphere is yet to be permitted in UKROFS standards.

As far as diseases are concerned onion neck rot (*Botrytis allii*) is sometimes a problem in organic crops and is also considered a risk in conventional crops.

2.4.2.2. Growing for storage

As with other crops, successful onion storage begins with crop planning, choice of varieties and correct husbandry practice. Some general points to promote successful storage are as follows:

1) Avoid disease.

- Practice crop rotation to prevent soil borne disease build-up.
- Use disease free seed.
- Avoid high populations which tend to encourage disease.
- Do not irrigate within 2-3 weeks of harvest to avoid diseases on the bulbs.
- Avoid overfeeding (not normally a problem in organic systems), this can lead to increased levels of fungal and bacterial rots and sprouting (Brice *et al.*, 1997).

2) Choose suitable varieties for storage and acceptability for the chosen market (see section 2.4.2.3).

3) Under cut about 2 weeks before harvest to promote drying of the foliage. Although yield is generally maximised if the leaves are left to die down naturally and completely dry out. On wet soils and under UK weather conditions, it is best to undercut and take a slight yield penalty .

4) Dry and cure the bulbs, this is essential before storage if it has been too wet to achieve field drying and airing. (see section 2.4.2.4). Do not put wet bulbs into storage.

5) Handle the onions carefully to avoid damage and bruising, even relatively hard varieties should not be dropped more than 1.2 m onto a hard surface (Isenberg, 1955).

2.4.2.3. Varieties (cultivars)

On the whole spring sown varieties store better and longer than autumn sown varieties which are adapted to bulb and mature in the shorter days of early summer. Onions which store for a long time tend to be high in dry matter, have high pungency and long dormancy (Currah & Proctor, 1990). There are exceptions such as some recently developed cultivars in Israel which combine long dormancy with relatively low dry-matter content. Sets generally mature about 2 weeks sooner (around mid-August) than sown onions so they are more likely to mature and cure in the field and hence there is more opportunity to get them into store.

Generally varieties suitable for storage should produce a number of dry outer skins. These help to prevent moisture loss (Brice *et al.*, 1997) and help provide a physical and chemically resistant barrier to pathogens. Some skins are inevitably lost during handling and storage, the more skins a variety has the more likely it is to have a skin when it reaches the consumer. Damaged or missing skins are generally down graded by the supermarket trade (HDC, 1993).

NIAB routinely test the storage longevity of conventionally grown onions entering their variety trials. Unfortunately, there is no data available for these varieties grown specifically under organic conditions. But these storage tests are reasonably relevant for the organic crop as they are carried out at ambient temperatures under barn storage conditions without the use of sprout suppressants. These conditions primarily test the varieties tendency to sprout rather than resistance to neck rot (for which there is very little information). These varieties are listed in the NIAB ‘Vegetable Variety Handbook’ (1997b), cost £15. The hand book should be referred to for other characteristics of the varieties such as yield, skin protection and shape.

Spring sown onions

Suitable for long term storage	Not suitable for long term storage
Bristol (HOW/VDH) Above average Caribo (SEG) Good Durco (SEG) Excellent (but can get rots) Macho (NIZ) Good Marco (NIZ) Very good Mistral (HOW/VDH) Above average Salado (NIZ) Good Spirit (BJO) Excellent Selhurst (S&G) Good (but can get rots)	Barito (RSL Cesar (HOW/VDH) Crossbow (ELS/HRI) Dinaro (RSL) Hyfast (BJO) Vitesso (NIZ)

Set Onions

Suitable for storage	Not suitable for storage
Jet Set (BJO) Good Sturon (SEG) Good Turbo (SEG) Good	Centurion (BJO) Jagro (BJO)

Organic grower experience has found that Sturon, field cures and stores very well (Tolhurst, 1997, pers. comm.), according to NIAB (1997b) and Horticultural Development Council (1992) (HDC) this variety also performs well in conventional trials.

HDC recently funded some work to look at the storage longevity of some North American varieties not normally available in the UK (HDC, 1992a). All varieties stored in an ambient air cooled system (0-8.9ºC) had begun to show internal sprouting by 18th of March. Of the UK varieties tried, Spirit and Sturon showed the least sprouting. All varieties put into cold store (0.5 to -1.5ºC) until the 14th of July had internal sprouting. Although some of the North American varieties Benchmark, Flame and XPH 3243 showed reduced sprouting, none appeared to completely solve the problem.

HDC is continuing to fund NIAB to do storage trials, preliminary results indicate that four new un-named varieties look promising in trials which were untreated with sprout suppressants (HDC, 1997). However, some of the HDC trials now use sprout suppressants and these results will be of limited value to organic growers. Varieties which respond well to sprout suppressants are not always the ones which store the best in their absence.

2.4.2.4. Drying and curing

Before storage, it is essential that the bulbs should be properly dried (i.e. surface moisture removed) and then cured (a process ideally between 27-30ºC and relative humidity at 70%) which promotes strong outer skins and the closure of the onion neck. Normally onions are harvested in August/September. In warm, dry weather drying and curing can take place together in the field. Onions from sets generally mature more rapidly than those grown from seed, consequently there is a longer window of opportunity to get them into store. Alternatively drying and curing can be achieved artificially using heated force draft ventilation.

The simplest method of drying is to loosen the onions from the soil when about 50% of the leaves have fallen over and then leave them to field wilt in wind rows for about 10 days. This initiates the curing process to dry off the skins and seal the neck. There is some debate as to which is best, field wilting or direct drying where the crop is lifted and loaded directly into store and all drying and curing is done artificially. Direct drying lessens the risk of the crop being exposed to rain and damp which can encourage further root formation and mould growth resulting in skin discoloration (Electricity Council, a). Drying in intense sunlight can also scorch onions causing discoloration and damage (Brice *et al.*, 1997) but this is normally a problem of the tropics not the UK. However, organic grower experience suggests that onions which have been dried slowly in the field in good weather conditions, generally store better and for a longer period of time, than those that have been dried quickly in artificial conditions and at relatively high temperatures (Tolhurst, 1997, pers. comm.).

The discrepancy about whether it is best to field dry or artificially dry may have arisen because direct harvesting involves the mechanical removal of leaves just before the onions mature. This is done to reduce the amount of excess foliage going into store (which can be up to 30% of store capacity in the undried state (Rickard & Wickens, 1977) but this sort of damage allows onion neck rot (*B. allii)*, as well as other diseases to enter the bulbs. If artificial drying is not carried out at the right temperature and airflow, an outbreak of neck rot can occur (Burchill, 1992). There are also reports from New Zealand (Harrow & Harris, 1969) and the USA (Hoyle, 1947) and a little more recently in the UK (Rickard & Wickens, 1977) that topping prior to storage increases the incidence of neck rot. There is also some evidence that topping also increases sprouting in onions stored until March in frost -free ambient temperatures (Rickard & Wickens, 1977).

To a certain extent it appears that the conventional practice of direct drying in store has made it necessary to top the crop in the field. This in turn has made the crop more prone to neck rot and sprouting, making it more necessary to use fungicides against neck rot and sprout suppressants such as maleic hydrazide.

In the light of this evidence the most sensible option for the organic crop is to undercut the onions about two weeks before harvest to promote rapid drying of the foliage and to field wilt and cure if at all possible.

For a small area of onions intended for storage e.g. up to half an acre, field drying can be promoted by growing the crop through a black plastic mulch. Not only does this provide effective weed control during crop growth but it also assists with field wilting and improves skin finish. This is probably because the absence of weeds assists airflow and the black plastic absorbs heat and it dries out quickly relative to the soil. The polythene can be left down and reused. There is usually enough residual moisture in the soil under the polythene for a subsequent crop such as pumpkin (Tolhurst, 1997, pers. comm.).

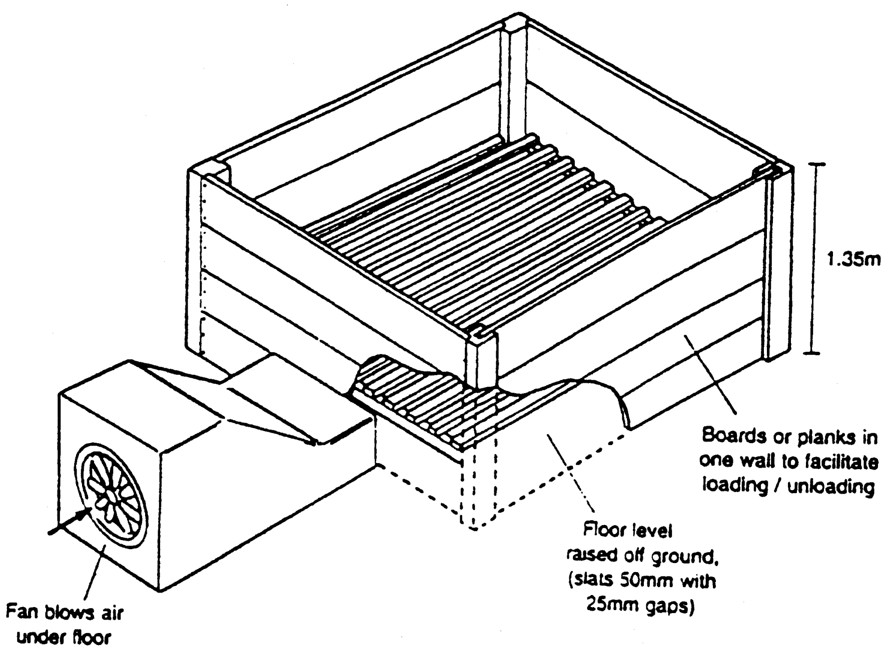
In suitable weather, onions can also be laid out in trays and stacked in the field to dry. There needs to be sufficient space between the trays to allow good ventilation. The onions can then be easily moved to cover if the weather becomes unsuitable. However, there is some cost for the trays.

For relatively small quantities of onions which are to be stored in relatively dry conditions with good air circulation, further curing is not necessary if field wilting has been successful (Tolhurst, 1997, pers. comm.).

Field drying will also save on electricity consumption actually during cool storage. It is estimated that the electricity consumption for field wilted onions in an ambient cooled store until March is approximately 120 kWh/tonne compared with 200 kWh/tonne for a directly harvested crop of onions. This does not include the cost of supplementary heating by gas or oil during drying (Electricity Council, a)

If weather conditions indicate that curing in the field is not going to be an option, a low cost method for curing a small amount of onions, is to lay them over a mesh duct or frame work and blow through warm air at 30°C. Dryers can be hired for this purpose. Drying above 30ºC is not advisable as higher temperatures encourage bacterial rots even if the relative humidity of the air used for drying is low. Black mould (*Aspergillus niger*) can also develop at temperatures above 32ºC, though this does not normally happen if the relative humidity is lower than 80% (Burchill, 1992). Ideally the relative humidity of the drying air should be below 60%.
Alternatively heated or ambient air can be blown through a bulk bin (see Figure 11)

Figure 11 Bulk bin drying using forced ventilation



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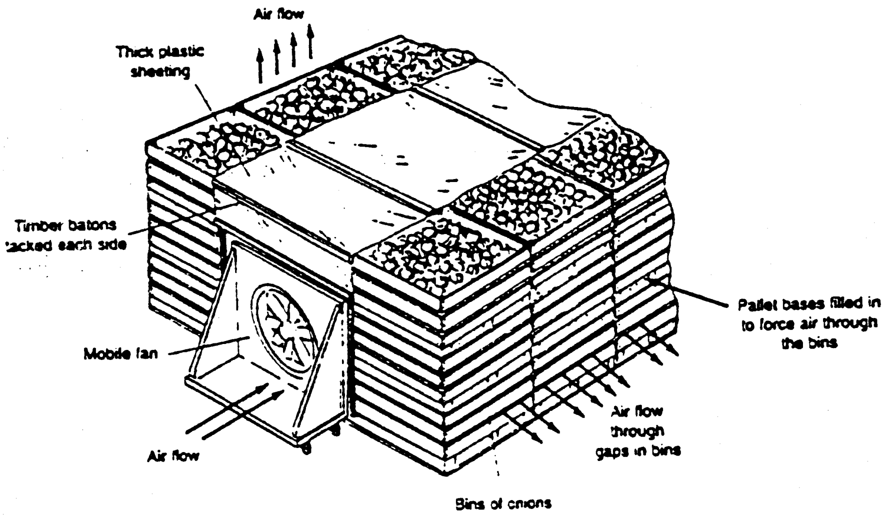
For larger quantities of onions intended for long term refrigerated storage, crops that have undergone a period of field wilting should ideally be dried in an airflow of 0.12 m^3/s/tonne with sufficient heat to maintain the humidity of the air at 70%. This should take between 3 and 5 days depending on how successful field wilting has been. The air flow should then be reduced to a ventilation rate of 0.047m^3/s/tonne using ambient unheated air to cool the crop to the required temperature (Electricity Council, a).

For crops where there has been no field wilting the crop should ideally be dried for about 4 days with air that is raised about 15°C above ambient temperatures to maintain a drying temperature of 30°C. Again the airflow needs to be 0.12 m^3/s/tonne during this phase. This is then followed by a second drying period for 4-6 weeks at slightly lower temperatures and a lower air flow rate of 0.047 m^3/s/tonne with air at 70-75% relative humidity to provide a temperature rise of 5.5°C (Electricity Council, a).

As an alternative to a specially constructed drying store, containers of onions can be stacked so that the fan and heater is fitted onto slatted boxes using polythene sheeting as a seal. The air is then forced through the stack and out through the sides of the boxes (see Figure 12).

Figure 12 Forced ventilation of multiple bulk bins



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Removal of tops

Small quantities of onions destined to be hung in strings should not be topped. Otherwise, the presence of tops in stores is not desirable because they affect the flow of the crop entering the store, require additional drying, take up storage space and create more wastage once the crop is graded out of store. If it is practical it is best to leave topping and trimming until the onions go into store but if they are to be direct dried, topping will have to take place before harvest. Topping should be done at 50-70% of leaf fall over (Brice *et al.*, 1997). This helps to avoid diseases such as neck rot and bacterial diseases from entering the bulbs. High topping (where the green leaves start to separate, about 10 cm above the bulb) and then bringing the onions into store to dry within 1 day of topping helps to reduce the risk of neck-rot. Undercutting is also advantageous (Rickard & Wickens, 1977). Great care should be taken to avoid damaging the bulbs themselves as this leads to increased respiration rates, skin loss and allows the entry of pathogens (Brice *et al.*, 1997). Drying should commence immediately the onions arrive in store or there will be rapid deterioration in quality.

2.2.2.6. Storage

Onions are unusual in that there are two temperature ranges at which they can be stored. Cool storage between 0 and 5ºC at relative humidity 65-75% is the best regime and generally the most practical and cost effective in the UK, but they can also be stored at 25- 30ºC (RH 65-75%) though losses from respiration and desiccation of the bulbs is much higher than that encountered at the lower temperatures. Between these temperature ranges (5-20ºC) sprouting is favoured (Brice *et al.*, 1997).

The recommended relative humidity for storage of onions is relatively low because it is one of the few crops that does not readily shrivel in low humidity storage and humidities of 70-75% generally help prevent onion storage diseases such as neck rot. Humidities below 65% cause shrivelling and loss of moisture, and consequently quality is reduced. Humidity has little effect on sprouting (HDC, 1992/93a) so if storage at a higher humidity is required in order to store the onions with other crops this should not have a detrimental effect on sprouting. But high humidities can promote root growth (Brice *et al*., 1997) causing some loss in quality and weight. However, if the bulbs are stored at too low a temperature e.g. -2ºC rather than 0ºC or 5ºC then not only is there a risk that the crop will freeze but once the onions are taken out of store they sprout much more quickly i.e. their shelf-life is reduced (HDC, 1992/93a). There is also the problem that onions can taint other crops if stored alongside them.

It is important that onions dried with warm air should be cooled to ambient temperatures (around 15°C) before going into store to avoid condensation, especially where cool storage is to be used.

The produce should be inspected before entering the store or clamp. Any damaged or diseased bulbs should be removed. It is also preferable to top onions at this stage, this may be practical by hand with a small amount of onions or mechanical toppers are available for larger quantities. They may also be graded. Smaller onions tend to store better than large ones (Tolhurst, 1997, pers. comm.).

1) Clamp storage (also see section 2.3.7)

Good ventilation to remove moisture and heat of respiration is essential for successful storage of onions. Raising the onions off the ground generally assists ventilation. This can be achieved by piling the onions on pallets covered with wire mesh or sacking, or a wooden lattice. The onions can then be covered with straw or an insulating quilt (see section 2.3.7.6). Bagging the onions not only helps with finding them and unloading the clamp, but can also be stacked to allow ventilation. Synthetic polypropylene nets allow more aeration than jute or sisal and allow easy visual examination. If natural ventilation is used the sacks should be filled to capacity so that the air spaces between the bags are at a maximum. The bags can also be stacked with channels between them to allow better ventilation.

If forced draft ventilation is to be used the bags should be slightly under filled so that they lay flatter, thereby reducing the gaps within the store making it easier to push the forced air through the sacks of onions.

2) Cool storage

Ideally for long term storage the crop should be held at 0°C, at a relative humidity of 70- 75% (the freezing point of the crop is -1°C). For storage until March controlled ventilation using ambient air is sufficient. For storage until June, refrigerated storage is required throughout or ambient air cooled storage until December and then switch to refrigerated cooling for the remainder of the period (Electricity Council, a). See section 2.3.15 for technical specifications for ambient air cooled and refrigerated bulk stores and pallet box stores.

Before the store is unloaded the onions should be allowed to warm over a period of 7 days until they are above the dew point temperature of the air outside or in the packing house. Again this helps prevent condensation forming on the bulbs. Onions are also more prone to bruising when they are cold (Brice *et al.*, 1997).

The current cool storage recommendations for onions (Electricity Council, a) are for conventional onions with sprout suppressants. HDC reports (1992/3a) and (1992a) indicate that internal sprout development in un-treated cool stored onions are not satisfactory for the supermarket trade. However, the practice of topping and artificial drying may have exacerbated the situation.

For ‘box schemes’ some internal sprouting is probably acceptable making cold storage of onions until June/July a viable option. The next crop of autumn sown onions is then available to cover requirements until August by which time the next crop of spring planted onions should be available.

3) Ambient air cooled systems

For loose bulk storage the onions should be piled up to a height of 3m. The walls of the building need to withstand the lateral thrust of the crop (approx. 1.57kN/m^2 per m depth). For storage up until March, cooling using ambient air is sufficient and thermal insulation is not required provided the building is dry and frost proof (Electricity Council, a)

2.4.2.7. Neck rot of onions

This disease sometimes occurs on organic stored onions. Organic practice such as rotations, less risk of excessive nitrogen in the soil, and low plant densities have probably helped to prevent it. However, it can be spread via contaminated seed and this could be a potential problem once organically produced seed has to be used by growers.

Grey-mould neck rot is most commonly caused by the fungus *Botrytis allii*, it also infects shallots, potatoes, onions, leeks and garlic. It is an air-borne, soil-borne and seed borne disease. Symptoms do not usually become noticeable until about 1 month after harvest, developing first as a semi-watery decay beginning in the neck area of the onion and then gradually moving down through the whole bulb. Often the decayed areas appear sunken and cooked. Scales become soft, water-soaked and translucent and a white to grey mycellial mat may develop between the scales. In humid conditions a layer of grey mould (conidia) appears on the outside of the onion. Hard black sclerotia may also form in a crust around the neck. The watery tissue affected soon dries out and a decayed bulb may take on the appearance of a 'mummy' (Schwartz & Mohan, 1995).

Although neck rot is primarily a storage disease, infection takes place in the field. The sclerotia overwinter on rotting bulbs or free in the soil. It is thought that these then sporulate to form infectious conidia and these infect plants while they are growing in the field. Infected plants may show no symptoms or only mild flecking of the leaves. Not only does this make it hard to tell whether the diseases is present in the crop, it also makes this phase of the disease hard to study. (One study showed a methyl red stain could be used to detect infections in symptom less onion tissue, mentioned in Schwartz & Mohan, 1995.) At harvest time if conditions are moist and cool and the necks of the onions are still succulent, they are very prone to infection if they come into contact with airborne conidia or soil infested with the sclerotia. The fungus can also enter through wounds.

Control

A test kit to detect levels of *Botrytis allii* prior to harvest is currently being developed and it is hoped that this will be ready for marketing in the near future (Lyons, 1997, pers. comm.). The results from the test kit can be used to help predict whether it is going to be worth storing a particular crop or not.

Only non-infected seed should be planted. Seed which is produced in arid areas is less likely to be contaminated. Seed dressed with fungicides e.g. Benomyl can also reduce neck rot, but the use of conventional seed in organic systems is being phased out and at present treated seed should not be used unless the variety cannot be obtained untreated.

Coloured varieties are generally less prone than white.

Practising rotations so that onions are not grown on the same land year after year helps prevent the build up of sclerotia in the soil.

Well cured onions with dried necks are rarely affected by neck rot. Practice which promote curing are:

- undercutting bulbs at maturity to sever all roots.
- applying no fertilizers later than 8-9 weeks after sowing (not usually practiced by organic growers anyway.)
- avoiding high plant densities (550,000 per ha is considered optimum).
- under wet conditions where the necks cannot cure well in the field, artificial drying, preferably with forced air, will be required.

Once in store temperatures of 15-20ºC will promote development (Walker, 1957). As free moisture on the bulb surface promotes the disease, great care must be taken to avoid condensation forming on the bulbs. Air which is at a higher temperature than the onions should not be moved through the store especially when the humidity is high. Ideally storage conditions should be 0-1ºC at 70-75% relative humidity to avoid the disease (Schwartz & Mohan, 1995).

There is experimental evidence that *Botrytis allii* spores produced at 0-5ºC rather than at 20ºC actually germinate faster and cause spoilage faster on wounded bulbs in cool storage at >95% humidity and once the bulbs are brought out of cold store (Bertolini & Tian, 1997). So although cool storage enables produce to be stored for relatively long periods of time, if the relative humidity in a cool store does not prevent conidial formation, storage life and shelf life may be reduced. Care must also be taken in grading lines that cross-infection does not occur between contaminated cool stored onions coming out of store with onions going into store.

2.4.2.8. Fusarium basal plate rot.

Fusarium basal plate rot is caused by *Fusarium oxysporum cepae*. Infected stem plates may show a brown discoloration. They may show no decay at harvest but then rot. As the disease progresses the bulbs appear discoloured and affected tissues go brown and watery. Infection usually takes place while the crop is growing in the field. It is primarily a soil borne disease but also can be spread via infected onion sets. It is not normally a problem when soil temperatures are below 15ºC.

Control

Store at 4ºC.

Rotation. Grow non-susceptible crops for 4 years if soil becomes infested.

(Schwartz & Mohan, 1995)

2.4.2.9. Black mould

Black mould is caused by the fungus *Aspergillus niger*. Symptoms normally start at the neck of the bulb with black discoloration and shallow lesions on the outer scales. Streaks of black mycelium and conidia tend to develop under the outer scales. In severe cases the whole of the bulb turns black. and the onion shrivels. Some bulbs appear unaffected from the outside but once cut discoloration can be seen in the middle of the onion which extends down from the neck.

It is usually only a problem in warm climates (30-35ºC) or under warm storage conditions (24-30ºC) where the relative humidity is above 78%. If relative humidity is below 76%, spore germination is prevented so its spread is restricted. Free moisture on the onion surface is also required for infection to take place. Temperatures below 15ºC halt the progress of infection but once the temperature is raised above this, the fungus will resume growth (Schwartz & Mohan, 1995).

Control

Store at temperatures below 15ºC.

Problems are most likely when the bulbs are above 24ºC e.g. during curing if RH is not kept below 75%.

Onions grown on soils with good levels of calcium are less prone.

Avoid damage at harvest.

No resistant cultivars are known but white cultivars are thought to be less susceptible than yellow, red or brown (Schwartz & Mohan, 1995).

2.4.2.10. Blue mould

Blue mould is caused by various species of *Penicillium* fungi. It is often associated with onions showing symptoms of neck rot but can also occur on its own. It usually develops in store but the bulbs tend to be infected in the field especially around harvest time. Some species can also be seed borne. The first symptoms of the disease appear on the bulbs as pale yellow blemishes, watery soft spots or sometimes purplish red staining on the scales. Later a green to blue/green mould may develop on the onions. When the bulb is cut some of the fleshy scales may appear water-soaked and be light tan or grey in colour. In the advanced stages the bulbs may disintegrate into a watery or rubbery mass. They usually smell musty.

Control

Prevent wounding and bruising at harvest.

Store at temperatures below 5ºC and at low a relative humidity.

Little is known about resistant cultivars. (Schwartz & Mohan, 1995)

2.4.2.11. Bacterial diseases

There are also a number of bacterial diseases such as slippery rot/soft rot (*Pseudomonas gladioli* pv *alliicola)*, soft rot (*Erwinia carotovora)*, and sour skin (*Pseudomonas cepacia*) which can also cause losses in store. Usually infection begins in the field if onions become damaged (by hail for example) or by damage and bruising at harvest. Often these bacteria are free living in soil and may also be spread around by irrigation water. The bacteria tend to grow best at higher temperatures (20-30ºC), such as those encountered during curing.

Control

Mechanical topping in the field, which is required for onions destined for artificial drying, may allow the bacteria to enter.

Drying should be done promptly.

Storage at 0ºC and less than 70% relative humidity prevents these diseases developing in store.

A test kit is now available for *Pseudomonas gladioli* pv *alliicola* from ADGEN Diagnostics (Cost approx. £150 for 250 tests). The grower can test the crop three weeks before harvest; the result from the test is ready 1 week before harvest and is used to predict whether the crop is worth storing or not.

2.4.2.12. Research areas

- Varieties for storage - organically grown & stored without fungicides or sprout suppressants
- Seed testing for clean seed
- Storage life of sets versus sown seed
- Novel methods of defoliation

2.4.3. Carrots

2.4.3.1. Current practice and problems

Carrots (both conventional and organic) are one of the few crops where there is a noticeable increase in price over the winter storage period, (see section 2.6, Figs 13 and 18) making storage a more viable proposition. However, storage of carrots is considered a problem for both organic and conventional growers. Long term storage (i.e. beyond March) of lifted carrots is possible using refrigeration but not without a loss in skin finish which is unacceptable for the washed carrot supermarket trade.

If the carrots are to be sold unwashed poor skin finish is obscured by soil and is not an important issue. This is the case in Holland, consequently Dutch growers find it worthwhile to lift their carrots and have a simple cool store on site. Deterioration in flavour also occurs in both field stored and cool stored carrots after March. Supermarket buyers are becoming aware of this, and it calls into question the viability of storage of the conventional UK crop beyond March. By this time a new seasons crop can be imported from Spain (HDC, 1993) .

The visual quality of field stored carrots is much better than those that have been lifted and stored. On suitable soils field storage can be used successfully until March. Consequently, most of the conventional crop put into storage in the UK (about 30% of the total crop grown, HDC, 1992/93b) is stored over winter in the field. Field storage is also practiced by some organic growers and they face much of the same technical and financial limitations as conventional growers.

Field storage is not possible on all soil types e.g. heavy soils tend to become water logged causing rots. In some areas bad weather can make lifting impossible for much of the winter so that marketing opportunities are missed altogether. In other cases lifting by hand during the winter may be feasible but this makes the operation expensive. Many organic carrot growers find themselves in this situation, often they are not on optimum soil types (peat or sand) for carrot growing or storage. These carrots have to be lifted by hand making them expensive and is one of the reasons why organic carrots increase dramatically in price over the winter.

Another drawback to field storage is the disposal of straw required for extra insulation. The amount of straw to be disposed can be quite substantial. As a result it is expensive, many tractor passes may be required to incorporate it into the soil. Incorporation of straw can also cause nutrient lock up while it breaks down.

The only alternative to field storage is to lift the carrots in autumn and clamp or cool store and accept a reduction in quality. Consequently, there is a need to develop simple cheap storage methods for lifted carrots which retain skin finish, enabling more organic growers to contemplate storage for the supermarket trade. In the long term this should bring prices down to a reasonable level for the consumer, enabling UK carrots to compete with imports and in turn stimulate greater demand.

Growers that direct market their carrots supply them unwashed, therefore they can lift their crop and have a wider range of storage options i.e. clamp storage or cool storage (see sections 2.3.7. & 2.3.10)

The development of carrot root-fly (*Psila rosae*) damage in store can also be a problem in organic carrots, especially those that are field stored. There are cultural methods which can be used by organic growers to help prevent infection in the field and hence avoid contaminated carrots being stored in the first place (see section 2.4.3.2).

Soil borne diseases such as violet root rot (*Rhizoctonia solani*) and cavity spot (*Pythium violae*) can also develop in store. The use of crop rotations in organic systems helps to reduce the incidence of these diseases, i.e. the same crop is not grown on the same land year after year.

2.4.3.2. Growing for storage.

1) Choose appropriate varieties.

Select varieties for the storage method to be adopted and those that show some resistance to carrot fly, violet root rot, cavity spot etc. Short varieties which are less likely to reach down to waterlogged soil and those that do not push their shoulders out of the ground are the most suitable for field storage.

2) Practice crop rotation.

This avoids the excessive build up of some of the pests and diseases which develop in store such as carrot fly, violet root rot & cavity spot.

3) Delayed sowing.

Delayed sowing can defer the onset of pests and disease during field storage. It is only beneficial to sow late (early/mid June) when adequate seed bed moisture can be guaranteed (i.e. irrigation) otherwise reductions in yield outweigh any delay in pest and disease development achieved in field storage (HDC, 1992/3b).

4) Avoid and control carrot fly.

The most effective way to control carrot fly is to use a crop cover, e.g. non-woven fleece or netting, preferably throughout crop growth. The most critical period is during the peak in the second generation of carrot fly. In most areas this means covering the crop from Mid July, throughout August and into mid September. Adults emerging after this time do not usually manage to lay eggs (Finch *et al.*, 1996, Finch & Collier, 1997). Covering the crop during the peak in the first carrot fly generation (May/early June) is of more limited benefit. ADAS run a carrot fly forecasting service which can be used to help make decisions on when to cover.

It is best to remove the fleece in the autumn so that humidity does not build up under the cover and cause rotting. It also allows the crop to cool down as much as possible before ridging or covering with straw for field storage over the winter.

The price of non-woven fleece is variable depending on quantity ordered at one time but should be in the region of 5.8-7.5p/m^2 for 17g weight (Gromax, 1997). Heavier weight fleece is also available and is more durable. Insect proof netting which can be used for more than one season and allows freer circulation of air, is also available at around 30-35p/m^2. The price fluctuates from year to year with the cost of the raw materials (Gromax, 1997). The cost of pegs to hold covers down and labour to lay fleece also needs to be taken into consideration.

Delaying sowing until the first generation of carrot fly has peaked, usually in late May/early June can be of some benefit where covering the crop with fleece is not practical. However, it is doubtful whether the benefits of reduced carrot fly damage compensate for the reduction in yield resulting from a late sowing (HDC, 1992/93b). Where adequate seed bed moisture can be guaranteed (e.g. irrigation), delayed sowing is likely to be more successful. Satisfactory, though not complete, carrot fly control has been achieved at HDRA using this method.

The use of crop rotations can also alleviate damage by carrot fly. Avoid growing other susceptible crops such as parsnip, celery and parsley close together in the rotation (Gratwick, 1992).

Heavily infested crops should not be left in the ground beyond November and should be fed to livestock or disposed of in such a way that the maggots cannot survive the winter (Gratwick, 1992).

Some carrot varieties are less attractive to carrot root fly than others, though none are immune. Nairobi, Newmarket and Sytan have consistently performed well as far as carrot fly resistance is concerned in organic NIAB variety trials. Unfortunately, Corrie, which is otherwise suitable for field storage because of frost tolerance, appears to be very attractive to carrot fly. It is therefore advisable to fleece this variety during crop growth.

5) Inspect the crop before storage.

Only select the best crops for storage. It is worthwhile to carry out thorough pest and disease assessments to identify crops which should not be stored. Violet root rot, cavity spot and carrot fly can often be detected before storage. Dig up a few carrots from several places in the field or bed as the distribution of these diseases is usually patchy. Wash soil off the carrots gently before inspection.

At present there is no benefit from carrying out mineral or sugar analysis before storage, reliable methods to predict how flavour deteriorates in store have not yet been developed (HDC, 1992/93b).

6) Avoid Grey mould. Grey mould caused by *Botrytis cinerea* can also be a problem in both clamp and cool stored crops which have been lifted in the wet. It is a weak pathogen and tends only to attack damaged, dehydrated or already diseased roots. Once the grey mould develops in store the spores are easily circulated in the air and can spread infection through the store. Do not store wet crops, avoid putting damaged carrots into store and do not allow leaf debris and litter into the store. Grey mould develops much more quickly in store than other diseases and its presence indicates that something is incorrect with the storage regime. Often temperatures have been allowed to rise or humidity has dropped and the carrots are no longer turgid.

2.4.3.3. Harvesting for storage

It is important that carrots lifted for storage are mature. Immature carrots will not store well, they soon dry out and shrivel.

1) Harvest and handle the crop carefully. Hand harvesting, although not practical on a large scale is beneficial for long term storage. Breakage is less likely and damaged or diseased carrots can be picked out as they are lifted. Severely damaged carrots should never be stored. Before postharvest chemical treatments were used in conventional carrots, mechanically harvested roots were only recommended for cool storage up until March (ADAS, 1980).

2) Harvest in good weather. Carrots intended for clamp or cool storage should be harvested under good weather and soil conditions. Trials in the past have shown that carrots harvested in cold wet weather and with large amounts of soil and plant debris attached, do not keep as well as roots lifted under dry conditions (ADAS, 1980).

2.4.3.4. Field storage

At present, field storage is the best available option for organic carrots destined for UK supermarkets. The most suitable soils for field storage are sand and peat. Heavy clay or silty soils are not usually suitable, they are too sticky when wet, so that lifting is not feasible for much of the winter in most areas of Britain.

The length of storage is dependent on weather conditions, but in most areas it is reliably successful up until March. As the soil warms during April and May pest and disease problems tend to build up, and there is a noticeable deterioration in flavour. Field storage can sometimes be successful up until May, but growers may well need to start clearing the land for the next crop from February/March onwards. During the coldest parts of the winter extra insulation is usually required. Cycles of freezing and thawing are more damaging to the crop than a period of constant low temperature, so a careful watch needs to be kept on the weather and protective measures taken if necessary, even in milder areas.

One of the major drawbacks of field storage is its cost. This is very variable depending on the amount of insulation required and materials available on the farm.

In milder areas and on some soils the carrots can simply be ridged up with earth to provide insulation from frosts. This method is relatively cheap and is usually used for carrots for lifting from

January onwards. Peaty soils are more effective insulators than sandy soils but even these are dark and tend to absorb heat in the spring causing the carrots to shoot. A minimum depth of 15cm of soil should be placed over the rows using a plough or ridger (ADAS, 1980). The row spacing needs to be a minimum of 50cm to allow ridging. The drainage of the soil must be very good where ridging is contemplated and a short variety (e.g. Camden or Corrie) is less likely to end up with its 'feet' in the water table and rot. Varieties which produce a shoulder that protrudes from the ground should also be avoided as these are hard to ridge (Chapman, 1996, pers. comm.)

In some areas which are mild but not humid, field stored carrots can be stored under fleece (30g weight). In Holland some growers cover the crop with a 17g fleece to keep out carrot fly during the summer and then lay down a second layer of 17g fleece before the first frosts are expected (Herrewijin, 1997, pers. comm.) However, most areas of Britain are too cold for this system to be effective and there is also the danger that humidity and rots may build up under the fleece.

Where the insulation properties of the soil are poor (e.g. sand), straw or polythene plus a layer of straw, is required to prevent freezing in the winter. Insulating the soil also delays warming of the crop in spring to a certain extent. The polythene and straw should not be laid down too early or the soil will remain too warm. Late November/early December is optimum in the east of the country before severe frosts are expected. If straw only is to be applied, it needs to be a minimum of 30cm deep. Conventional growers use on average 40t/ha of straw (up to 80t/ha of straw is not unknown) this can become very expensive if the straw needs to be bought in (e.g. £92/ha for 40t/ha of straw) and then disposed. Straw burning is not permitted under UKROFS organic standards. For small areas e.g. 0.2ha, it is feasible to remove the straw and compost it (Chapman, 1996, pers. comm.).

On a larger scale the only real option is to incorporate the straw. In HDC funded trials (HDC, 1991/92) it took up to 9 passes to incorporate 40t/ha of unchopped straw. It is estimated that this could cost between £80-250 per ha. This number of passes would not be advocated by organic growers who generally wish to reduce cultivations to a minimum in order to maximise microbial activity in the soil and maintain soil structure.

In some areas growers could use less straw. Ridging the crop can reduce the amount of straw required, under these circumstances the minimum amount of straw that can be used is about a 6” layer (approx. 17.5 t/ha on a bed system). Grower experience (Chapman, 1996, pers. comm.) has found that this is sufficient for brief periods of cold down to -8ºC. Black polythene (and a more recent development, paper mulch) can be laid over the crop to prevent wind penetration, providing some insulation and reducing the amount of straw required on top (usually 25 t/ha of straw is laid over polythene). Condensation and warmth can build up under the polythene and the results of HDC trials, (HDC, 1987/89) indicate that cavity spot and carrot fly damage tended to be worse with crops stored under polythene and straw than those which were stored under straw alone. The advantage of using black polythene is that it cuts out light to help stop re-growth and the soil is kept dry underneath, enabling lifting when soil conditions would otherwise be too wet.

Chopping the straw before incorporation also helps reduce the number of cultivations required (HDC, 1991/92). Machinery for this purpose, with and without polythene is being developed by Kverneland (UK) Ltd, Rotherham, South Yorks.

An additional problem for organic growers is that the yield of the following crop can be adversely affected. 'Nitrogen lock up' is likely to occur where large quantities of straw are incorporated into the soil. In conventional systems applications of nitrogen fertilizer to the following crop (but not to the straw itself) helps to alleviate the effect (HDC, 1991/92). It is not known whether applications of farm yard manure, compost or other fertilizers acceptable to the organic standards would work. Most organic fertilizers contain nitrogen that is released slowly, so it is unlikely that they will alleviate the problem. The duration of nutrient lock-up is also unknown. In some mixed arable/vegetable systems a possible solution may be to follow field stored carrots with a low nitrogen demanding crop such as a clover seed crop. This has not yet been proven and may not be a realistic option for a more intensive vegetable rotation. Alternatively carrots could be inserted into the rotation just before returning to a fertility building crop e.g. grass/clover ley. Carrots often appear late in an organic rotation anyway, if soil nutrients are high carrots tend to fork. However, the growth of the fertility building crop may also be affected by the straw and the success of the fertility building phase of the rotation is critical in organic systems, especially those which are stockless.

There is also some concern that pests such as carrot fly and diseases such as violet root rot, cavity spot and bacterial rots may increase during field storage. The incidence of these problems probably do not reach significant proportions until March. In a trial funded by HDC (1992/93b) where black plastic and straw (at least 25t/ha) were used. Marketable yield reductions were only between 5% and 20% by May.

In conventionally grown carrots, which were sprayed with Fubol against cavity spot soon after drilling, the incidence of diseases such as violet root rot, cavity spot and bacterial rots tended to remain low from October through to February/ March. Noticeable increases in these diseases during field storage occurred during April and May when soil temperatures rose (HDC, 1992/93b & HDC, 1987/89).

In the same trial the incidence of carrot fly started to increase from January onwards but the increase was not significant (HDC, 1992/93b). Attempts at spraying against carrot fly were not regarded as successful during this trial, so the results can be considered of some relevance to organic production, at least with respect to carrot fly damage.

2.4.3.6. Clamp storage

Carrots can be stored in outside clamps until March but the skin finish on lifted carrots is never as bright as those that are field stored. Likewise the quality of clamp stored carrots is very unlikely to be of the same quality as cool stored carrots. There are circumstances where clamp storage may be useful. For example for growers on heavy soil or where the weather is likely to make harvesting out of field storage impossible over the winter or where the water table is high so that the roots rot if left in the field.

As with other forms of storage only pest and disease free carrots should be stored. Unwashed carrots usually store better than washed. If it is at all practical the carrots should be covered with earth (15cm to 20cm thick). Straw should not be used (ADAS, 1980) as it tends to cause increased shrivelling and rotting. The base of the crop pile should be a maximum of 1.5m wide and have a maximum height of 1.3m. For smaller quantities of carrots to be loaded and removed by hand, placing the crop in nets makes retrieval from the earth easier. Protection against vermin may be necessary (ADAS, 1980).

Carrots can also be stored for short periods inside barns in clamps. This can be useful where relatively small quantities of carrots have been bought in for a box scheme and are expected to be used within 6-8 weeks (Schnabel, 1997, pers. comm.).

Clamp storage within a barn can also be useful where carrots are essentially field stored or stored in a clamp outside but a period of weather is expected which will make lifting or opening a clamp outside impossible. Enough carrots can be lifted to supply a box scheme or farm shop for the problem period (Tolhurst, 1997, pers. comm.).

It is not always practical to store even small quantities of carrots indoors using soil, a covering of straw may be required instead. Grower experience with inside clamps covered with straw has found this method unreliable, with the carrots sprouting, rotting and showing heavy fly damage by February (Chapman, 1996, pers. comm. 1996, & Schnabel, 1997, pers. comm.).

Also more sophisticated clamps for storage of carrots have not been found to be effective. For example ducted clamps, ventilated by either ambient or chilled air were reported as not being very successful in 1972 (ADAS, 1972).

Alternative solutions may be to store carrots in sand, a traditional method for storage of small quantities of carrots was to place them in barrels of damp sand.

An adaptation of this would be to store carrots in a pit of damp sand. Carrots along with some extra soil could also be stored in bulk bags placed within a fairly permanent pit. These would be relatively easy to load and unload with a suitable fork loader attachment on a tractor. The method has been tried in Eastern Europe but needs development work (Tolhurst, 1997, pers. comm.).

2.4.3.6. Cool storage

Humidified refrigeration is most appropriate for long term storage of carrots. Storage up until May and June is possible in conventional carrots. Before the use of fungicidal dips introduced in the 1970's (e.g. Benomyl), cool storage of conventional carrots for more than 5 months was unpredictable (Derbyshire & Crisp, 1978). Levels of rots caused by fungi such as *Botrytis cinerea, Mycocentrospora acerina* and *Sclerotinia sclerotiorum* were the main problem and could cause up to 30% losses depending on initial infection levels going into store (Derbyshire & Crisp, 1978). These diseases are often more problematic where root crops are grown in close rotation or the humidity in store is not sufficient to prevent loss of turgidity and hence entry to the roots by the pathogens. If the crop is inspected for disease, harvested carefully under dry conditions, and temperature and humidity maintained in cool stores, then storage of organic carrots until June should be possible. The method and levels of damage at harvesting are critical for long term storage. Hand harvesting is beneficial, though it is appreciated this is not practical for large tonnage's.

There are indications that the flavour and sugar content of long term cool stored carrots is better than carrots which are stored in the field beyond March. Long term field stored carrots also tend to be more woody (HDC, 1987/89).

Cool storage also has the advantage that it can provide supplies when bad weather prevents harvesting of field stored carrots or the opening of outside clamps. Cool storage can also supply the processing industry where good skin finish is not so essential.

The main problems with cool storage are poor skin finish, dehydration and disease. Poor skin finish is more severe on crops grown in sandy soils as abrasion during lifting and washing is more likely. There are also indications that rots and shooting develop more rapidly once the carrots come out of store, reducing shelf life of cool stored carrots in comparison to field stored up until March. But beyond March field stored carrots deteriorated more rapidly in shelf life tests than cool stored carrots. This probably reflects the overall increase in pests and diseases that occurs as soil temperatures increase in the spring (HDC, 1987/89).

Ideally the cool store should be held at 0-1ºC and at 95-98% relative humidity (FarmElectric, b). This can really only be achieved reliably using refrigerated storage. In practice it can be difficult to maintain humidity at 95%. Carrots are very prone to dehydration and shrivelling, a weight loss of 8% will severely affect crop quality. Consequently it is worthwhile having a humidifying system in the cool store. Carrots are usually stored in bulk containers of either 500kg or 1000kg. Nets are not advisable as they tend to make airflow uneven (ADAS, 1980).

Refrigerated stores that have humidifying systems are the most appropriate storage method. Pad humidifiers are preferable to spray humidifiers or freezing fog systems as these carry no risk of wetting the crop which can lead to rots. Moist air cooling systems are also appropriate for carrots as they achieve crop cooling without dehydration. For box stores a combination of moist air cooling and positive ventilation is required (FarmElectric, a).

Where it is not possible to maintain humidity at 95-98%, bulk bins can be lined with polythene to help maintain humidity within the crop. Derbyshire & Crisp (1978) showed that conventionally grown undipped carrots generally cool stored (1.1ºC at RH 90%) better in polythene lined bins than unlined bins. The results were variable ranging from 2.9-30.5% rotten in lined bins as opposed to 21.6-41.1% rotten in unlined bins. Temperatures in the lined bins were higher (2.2ºC) but the carrots remained more turgid and as a result there was a lower incidence of rots, especially *Botrytis cinerea* after 7 months storage. However, slight root and shoot growth did occur in the carrots stored in lined bins for more than 5 months.

Alternatively, polythene sheeting can be used to wrap the outside of the bins. This can be useful where carrots are stored with other crops that can tolerate lower humidities. More development work is required in this area.

2.4.3.7. Hydrocooling

Hydrocooling can be used to rapidly cool a crop. The crop is bathed or drenched in cold water which is kept at optimum temperature using refrigeration equipment. The crop then has to be dried using sponge rollers or high velocity air jets (FarmElectric, a)

Since carrots are sold washed to the UK supermarket, hydrocooling is a suitable method for both cooling and washing the crop before transient cool storage or distribution. This method is expensive and only worthwhile for packers or co-operatives handling large volumes. Washed carrots are not suitable for long term storage as they rot and shrivel more quickly.

Ideally crops should be graded and diseased roots removed before hydrocooling as spores of fungal rots such as violet root rot are easily spread from root to root. If condensation subsequently develops in the pre-packs or they are left in the warm, rots can quickly develop and reduce shelf-life. In this respect one may think it is not suitable for organic produce, but the packers Organic Farm Foods, currently use this method successfully (Segger, 1996, pers. comm.). It has also been shown that, in conventionally grown carrots, levels of rotting are lower in those that are hydrocooled than those washed in water at ambient temperature (HDC, 1992b).

HDC funded work (HDC, 1992b) showed that hydrocooling as opposed to washing in water at ambient temperature helps prevent turgidity loss, deterioration of skin finish, and rotting in shelf life trials. Hydrocooling with either sodium hypochlorite or chlorine dioxide added to the water further reduced rotting in shelf life trials and contamination of the washing water. Chlorine dioxide was usually better at reducing rotting than sodium hypochlorite. Chloride residues on the carrots used in the trial were similar whether treated with ordinary water, sodium hypochlorite (at 200ppm) or chlorine dioxide (Purogene at 25ppm). Sodium hypochlorite is permitted in the organic standards for cleaning equipment but it must be thoroughly washed after use. It is unlikely to be permitted for washing vegetables under UKROFS standards.

2.4.3.8. Modified atmosphere

Use of modified atmosphere packaging may help where a grower has a basic cool store or wishes to store carrots with other vegetables. The modified atmosphere inside the bags could slow the development of fungal diseases and sprouting (Cole, 1971).

2.4.3.9. Research areas.

1) Low cost alternatives to cool storage.

- Modified clamp/ pit storage.
- Lift the carrots with plenty of earth to prevent drying out and put them ungraded into one tonne boxes (different types of boxes could be tried). Dig a partial pit, place soil over and leave until required. This method has never been attempted as far as is known. Opening the clamp would still be weather dependent, though to a lesser degree than field storage. Machinery suitable for lifting tonne boxes would be required. (Suggested by Peter Segger of Organic Farm Foods)
- Bulk bags in a pit.
- Storage in sand.

2) Methods of straw disposal and Incorporation of straw.

The feasibility of incorporating various quantities of straw and different soil types with the minimum of cultivations and cultivation depths.

3) Nitrogen lock up and ways of overcoming it following straw incorporation.

Severity and duration of ‘nitrogen lock up’. Applications of organically accepted fertilizers. Suitable crops/fertility building crops to follow straw incorporation. Suitable rotations to avoid nutrient lock-up.

4) Detection and estimation of levels of storage diseases in crop and soil.

Already addressed by conventional research but incidence levels considered to cause problems may need to be adjusted for organic systems.

2.4.4. Parsnips

2.4.4.1. Current practice and problems

Parsnips can be stored successfully in the field but once removed from the soil and washed they suffer a rapid deterioration in colour which is a very noticeable problem for the pre-pack market. The crop needs to be harvested, washed and packed on the same day to ensure it reaches the shop without discolouring. This is also a problem for conventional produce and technology is not available to solve it.

2.4.4.2. Growing for storage

Many of the diseases and pests which attack carrots are also a problem for parsnips, and can be avoided in the same way (see section 2.4.3.2 for general control methods e.g. resistant varieties, clean seed, use fleece to control carrot fly, practice crop rotation, avoid damage at harvest, only store a healthy crop).

2.4.4.3. Field storage

If practical for the particular site, field storage is the best available method for parsnips at present (Tolhurst, 1997, pers. comm.). Parsnips generally store well in the field, they do not require covering with straw or other materials as they are tolerant of frosts, freezing and thawing, and tend to grow deeper under the soil than carrots. Therefore there are none of the costs or problems associated with incorporating straw as with field storage of carrots. Parsnips will usually remain in satisfactory condition until the end of April after which time the tops regrow and the roots become woody (ADAS, 1984b). Parsnips field stored in sandy soils can be lifted at any time during the winter but this may be a problem on heavier soils. If wet weather is likely, enough roots can be lifted to supply a box-scheme or farm shop for 2-3 weeks and stored in clamps in a barn, or for longer if a cold store is available.

Parsnips dry out very quickly once lifted, so long term storage in clamps is not successful.

2.4.4.4. Refrigerated storage

For growers on soils unsuitable for field storage, refrigerated storage is an option if the roots are to be sold unwashed. Skin finish of parsnips deteriorates even more quickly than carrots once they are lifted from the soil. Ideal storage conditions for parsnips are 0-2ºC and a relative humidity of above 95%, preferably 95-98%. They can store for up to 4-6 months under these conditions (Thompson, 1996).

As with refrigerated storage of carrots, parsnips may benefit from being stored with relatively large amounts of soil. This is only advisable if the crop appears very healthy and undamaged.

2.4.5. Swedes.

2.4.5.1. Current practice and problems

Swedes can be field stored but there are very few organic growers on suitable soil types or who are in areas cool enough to store beyond March. Normally the price of swedes would not make it a worthwhile crop to cool store, but out of season swede (spring and early summer) fetches a good price in the supermarket trade and it would be worthwhile to develop a low cost storage method to enable growers who cannot field store to supply this market.

2.4.5.2. Field storage

Swedes generally survive freezing quite well and will field store in the south-west, on land that is above 130-170m. Mild areas are not so suitable as they are not cold enough to prevent sprouting.

2.4.5.3. Clamp storage

Swedes can be stored in clamps until March. They should be harvested in mid November, or from September onwards, provided the ground temperature has fallen. This way the roots will be cool going into the clamp. The tops should be screwed off but roots left on. The clamp is best constructed outside, as the roots are less likely to dry out. The pile can be constructed on a concrete pad to assist loading and unloading, and covered with straw, either loose or small bales (Tolhurst, 1997, pers. comm.).

For smaller quantities of up to two tonnes, the swedes can be packed into nets and stacked. The stack can then be covered with loose straw. Again the clamp is best constructed outside and needs no protection from the wet.

2.4.5.5. Refrigerated storage

For longer term storage to supply the market from the end of March until May, refrigerated storage is required. Storage at 0.5ºC is required to prevent sprouting, and a high relative humidity of 97-98% is optimum. Storage can be up to 34-38 weeks under these conditions (Thompson, 1996).

2.4.5.5. Varieties for storage

Varieties with high dry matter usually store better than ones with low. From preliminary NIAB trials on organic grown swedes ‘Helenor’ and ‘Invitation’ appear to produce reasonable yields and have good frost tolerance. ‘Invitation’ has the added advantage that it has good club-root and powdery mildew resistance (Baines, 1997).

2.4.6. Cabbage

2.4.6.1. Current practice and problems

Cabbage is one of the few organic crops that can suffer brief periods of oversupply (Segger, 1997, pers. comm.). Generally it is not considered worthwhile to store summer cabbage as the greatest demand is for cabbage over the winter period (January to April). Even with refrigerated storage summer cabbage does not usually store more than about 20 days (ADAS, 1982). Storage of winter white and red cabbage is more feasible and could enable more of the organic UK market to be supplied by UK growers.

Cabbage is vulnerable to storage disease and rots. *Botrytis, Alternaria, Phytophthora porri* and bacterial rots are the most common problems. Conventional cabbage is often drenched with fungicides to help prevent these diseases developing in store. There are concerns that it may not be possible to store organic cabbage without these pesticides. Fortunately, there are some organic management practice which help to avoid these diseases. (See Sections 2.4.6.2 - 2.4.6.7).

Viruses have also been identified as causing problems in storage of conventional cabbage e.g. cauliflower mosaic and turnip mosaic viruses can cause blackened spots or areas (sometimes described as ‘cigar burn’)which develop inside the heads during storage.

2.4.6.2. Storage of summer cabbage

On the whole summer cabbage does not store well and does not stand in the field long. Supply of summer cabbage is better met by a good cropping programme and choosing later maturing varieties which tend to stand better in the field (up to 4-6 weeks) than early maturing varieties. Cabbage is best stored untrimmed, only the very outer leaves are left in the field when they are cut. Summer cabbage can be stored for a short period (up to 20 days) in refrigerated storage (0-1ºC at RH 95%). Further trimming is then usually necessary after storage (ADAS, 1982).

2.4.6.3. Field storage

Winter white cabbage is unable to withstand winter frosts, and should normally be harvested and in store by mid November (ADAS, 1984a). Alternate frosting and thawing quickly causes rotting. Some growers advocate that they can store cabbage in the field well into the winter but even in mild areas this is considered a high risk practice. Field storage even in mild areas is not recommended beyond early to mid December. Recent attempts to prolong field storage in conventionally grown cabbage by covering with fleece in February were unsuccessful. Rotting due to damage by previous frosts was actually increased. Covering with fleece on 9th December before frosts had set in was more successful but still gave a slight reduction in marketable yield (HDC, 1991/93). The same trial indicated that delaying sowing and transplanting beyond the traditional date for the region (Yorkshire) i.e. transplanting by mid July did not extend the field storage period, infact bolting was increased for crops transplanted after mid July (HDC, 1991/93).

Savoy, January King and winter hybrids usually withstand winter conditions better than winter white cabbages. They are therefore more suitable for field storage and are especially suitable for box schemes where cosmetic standards are not so critical. Savoy and hybrid savoy types such as ‘Celtic’ and ‘Tundra’ can stand in the field until Christmas. January King types are the most hardy and can stand in the field until March. Cooler parts of the country are generally better for field storage than milder areas as it is the mild weather in the spring and lengthening days which cause bolting. Cycles of freezing and thawing in mild areas can cause more damage than prolonged periods of cold. Large cabbages are usually best for field storage, so that there is plenty of scope for trimming. Often the outer leaves need to be heavily trimmed as these tend to dry out or rot. The cabbage inside tends to remain healthy and is of suitable quality for box schemes.

Bird damage can become a problem in over wintered cabbage. Fleece, netting or a bird scarer can be used as deterrents.

2.4.6.4. Varieties for storage

The requirements of the market need to be carefully considered when choosing varieties for storage. Supermarkets generally require head weights out of store of around 1kg or less, but box schemes can make use of a range of head sizes. Ideally varieties for storage should be more or less round, solid and show low losses due to trimming desiccation or decay. Similar sized heads which are easy to peel are also preferred. For organic production it is important that resistance to fungal diseases and viruses are considered when assessing a variety for storage. This is also becoming more important for conventional production as the numbers of permitted postharvest fungicides are gradually being reduced.

Varieties of winter cabbage vary quite markedly in their ability to store. Older varieties found to be suitable for storage are as follows:

Winter Whites for field standing - Jupiter, Bartolo, Langedijk 4 - Starkwinter (ADAS,1984a)

Winter Whites for storage: Bartolo, Polinuis, Bison (ADAS, 1984), Hidena, Winter white III, Langedijik - Decema (Davies, 1975b)

More recent variety trials (HDC, 1995/96) provided the following information:

Winter whites good for field standing: Impuls (Bejo), Kalorama (Howe/GZG Marne), Kilor (S&G), Scandia (Daehnfeldt)

Winter whites with poor field standing: Delus (Royal), Bison (Nickerson), Lion (Nickerson), Milord (Clause), Klaas (Royal)

Winter whites good for cool storage: Bison (Nickerson), Implus (Bejo), Slawdena (Bejo)

Winter whites poor for cool storage: Delus (Royal), Lion (Nickerson), Klaas (Royal)

Whites x Savoy good for field standing: Tundra (Nickerson) (HDC, 1991/93) & Celtic

Also trials by HDC (HDC, 1995/96) indicated that red cabbage did not store as well as white (grown conventionally but no postharvest fungicidal treatments mentioned). The varieties were assessed for both field standing and refrigerated storage (-1 to +1ºC) until mid June. Varieties which field stored well did not necessarily cool store well.

A few of the above varieties have been grown in NIAB organic variety trials, but storage was not examined. 'Delus' for example gave good yields in organic trials but is susceptible to *Botrytis* and rots making it unsuitable for storage. Its poor storage quality was also revealed in the conventional trials (HDC, 1995/96). The yield of 'Bison' tended to vary from year to year in organic trials (NIAB, 1992/93) but it is considered suitable for storage (HDC, 1995/96). More vigorous larger varieties such as 'Marathon' (S&G) and 'Impala' (Bejo) may be more suitable to use where conditions require more vigour or large heads for processing or a box scheme.

2.4.6.5. Avoiding disease in storage

Use clean seed. Diseases such as *Alternaria* (leaf spot) are seed borne (ADAS, 1984a)

Practice good rotations. Where brassicas overlap in the rotation or are grown close to other hosts including oilseed rape *Alternaria* tends to be more common (ADAS, 1984a).

Cauliflower mosaic and turnip mosaic viruses which cause blackened spots or 'cigar burn' in stored cabbage are spread by aphids. Continuous brassicae cropping tends to cause virus build up. Wherever possible overwintered crops should be destroyed straight after harvest and seed beds should be isolated from maturing brassicas by at least 100m (ADAS, 1984a). Covering seed beds with non-woven fleece should keep aphids off and help prevent cabbage root fly.

Any heads which look as though they carry disease should not be placed in store. Careful grading and handling is essential to prevent rots developing later.

2.4.6.6. Growing for storage

Winter white cabbage crops for storage are required for harvesting from around mid- October to mid-November. To achieve this, seed for transplants raised in frames or under cold glass, should be sown between the 20th and 25th of April. Bareroot transplants raised outside should be sown early to mid April. Transplanting should be complete by the 3rd week of June. Drilled crops in situe should be sown during late April-early May. For crops left to stand outside during the winter, drilled crops can be sown mid May but there is an increased risk of loose heads at this later sowing date (ADAS, 1984a).

Savoys, January King and Winter Hybrids are sown later than winter whites because they can easily become over mature. See Table 15.

Table 15 Suggested sowing, drilling and transplanting dates for winter cabbage

Crop	Frames or cold glass	Outdoor seedbed	Field drilled	Transplanting completed by
Winter white for storage	20 - 25 April	early- mid April	late April - early May	3rd week June
Winter white for standing*	early May	late April	early - mid May	end of June
Savoy, January King	early-mid June	mid- late May	late May - early June	3rd week of July
Winter hybrid	mid June	late May - mid June	June	end of July

(ADAS, 1984a)

*Loose heads can result from these sowings.

As gently sloping north facing aspects are usually cooler than other slopes this can be used to advantage for late winter crops to delay maturity (ADAS, 1984a).

Correct levels of fertilizer should be used. There are some indications that cabbage which have had high levels of nitrogen applied do not store as well as those with lower levels (ADAS, 1976).

2.4.6.7. Harvesting for storage

Cabbage should not be harvested over mature or with frost damage. Over mature cabbage is more prone to tip burn, the brown tissue soon becomes colonised by *Botrytis* and other rots. Harvest in dry weather and avoid including debris in the store. Diseases can be brought in on the debris and it can interfere with air flow within a store, leading to condensation which in turn encourages rots to develop.

Make sure that all boxes are clean. Cleanliness and careful handling is essential at all stages.

Handle the cabbage carefully at harvest and make sure they are not forced into crates or boxes. Trials in the 1970's designed to test the efficacy of pre-storage fungicidal treatments found that most of the problems associated with long term refrigerated storage of winter white cabbage could be avoided by very careful handling prior to storage rather than treating with the various fungicides tested (Davies, 1974a & 1975a).

The cut cabbage should not come into contact with the soil which is a source of many opportunistic fungi and bacteria this avoids rots. Cutting knives should not be stuck into the ground when not in use to avoid mud being smeared across the butt of the cabbage when it is cut.

It is best to pack the cabbage straight into the boxes or containers in which they are to be stored. They should be packed carefully so that the cut stems do not rest directly on their neighbours which causes damage. The cutter should not leave a butt longer than 13mm to avoid damaging other heads. Any wounded or bruised areas will rot. The cabbages should not be thrown into boxes or trailers, and should be rolled rather than tipped from trailers into store. Care at this time will be repaid by lower storage and trimming losses (ADAS, 1984a). If the cabbage are to be kept in a bulk store they should be loaded carefully into a clean trailer for transport, ready for stacking in a heap over air ducts.

Other than the loose outer leaves left behind in the field at cutting, only damaged leaves should be removed, the cabbage should not be trimmed before storage. This is because although the outer leaves are susceptible to water loss, once they dry out they act a bit like onion scales and reduce further evaporation (Robinson *et al.*, 1975).

Stores, whether clamp or refrigerated should be loaded early in the day so that field heat is at a minimum. Field trials have indicated that small cabbages tend to store better than large ones (ADAS, 1976).

2.4.6.8. Barn storage

For crops cut in November it is possible to simply store in barns until the end of March (ADAS, 1984a). This was also regarded as possible in 1976 before the more widespread use of pre-storage fungicidal dips (ADAS, 1976). The cabbage can be carefully stacked in boxes in an airy but frost free barn. Some organic growers have had success simply storing the cabbage in a trailer. The heads are then trimmed as they come out of storage. This can be a very labour intensive process. Trials at Luddington E.H.S on varieties suitable for barn storage successfully stored cabbage from 23 November until 4 April in bulk bins surrounded by straw bales inside a packhouse at ambient temperatures. Total storage losses including rots, trimmings and desiccation were around 34-40% (Davies, 1974a). ‘Decema’ and ‘Winter Pride’ suffered fewer losses than ‘Hydena’ or ‘Bewama’ but ‘Hydena’ and ‘Bewama’ remained firmer (Davies, 1974a). (Conventionally grown but no mention of pre-storage fungicides).

Some form of forced air circulation whereby cool air is intermittently blown through the crop to keep it cool until March was considered worthwhile for conventional crops (ADAS, 1984a).

2.4.6.9. Clamp storage

Outside storage clamps should not exceed 1.2-1.5 metres deep. In barns the depth of the stored heap may be up to 2.4m (ADAS, 1976) (See section above 2.4.6.8 and section 2.3.7 for more information on clamp storage).

2.4.6.10. Cool storage

For storage until April and through to July, refrigerated storage is required. The expected length of storage varies quite considerably in the literature, even where optimum temperatures and humidity are quoted as being similar. Discrepancies are probably due to different varieties under test, the condition of the crop going into store, the use of postharvest fungicidal treatments and differing perceptions of what is marketable. For white cabbage, optimum conditions are 0ºC at 100% RH for a storage period of up to 36 weeks. In practice temperatures of 1ºC to 2ºC and an RH of >95% is more likely to be achieved, under these conditions storage is more likely to be 25 weeks.

In the absence of pre-storage fungicidal treatments total storage losses of white cabbage after 8 months in a cool store running at 1ºC and 88-95% RH were in the region of 30% for varieties which store well and up to 60% for those considered not to store well. Total losses included desiccation, rots and trimmings (see Table 16) (Davies, 1975b).

Savoy cabbages do not keep as long, at -2ºC and 90-95% RH they can store up to 120 days. At 0ºC they can store up to about 40 days (Mercantilia, 1989).

2.4.6.11. Marketing

The butt and the outer leaves of the cabbage will need trimming after storage before they are marketed, this can produce a considerable labour cost.

Table 16 Average weight losses during storage and subsequent trimming (% of loaded weight)

Storage method	Desiccation (%)	Trimming(%)	Total(%)
Barn storage to March	8	17 - 27	25 - 35
Cool storage to March with fungicide drench	7	15 - 20	22 - 27

(ADAS, 1984a)

2.4.7. Beetroot

2.4.7.1. Current practice and problems

The storage of organic beetroot is not considered to be a particular problem. It can be stored successfully in clamps until March, in ambient air cooled storage until April, and in refrigerated storage until July.

Like the conventional market the wholesale market for organic beetroot is not particularly strong, though this may change with increasing interest from the processing market. Conventional prices of beetroot rise considerably from March until June (HDC, 1990) organic prices can also rise over this period but not every year (see section 2.6, Figure 21). Consequently, refrigerated storage of organic beetroot may be worthwhile in some years.

The success of storing conventional beetroot varies considerably from year to year, storage losses of up to 40% have been reported (HDC, 1991-1994). Desiccation and loss of dry matter are the main factors causing loss in quality after Christmas, especially when ambient temperatures rise. Storage diseases are sporadic, *Phoma betae* (canker), *Botrytis cinerea* (grey mould rot) and *Streptomyces scabies* are the main problems in conventional crops. There has recently been a trend for conventional beetroot to be produced on relatively few holdings, 70% of the conventional crop is grown on a small number of farms where there is little opportunity to practice rotations. The lack of crop rotation causes a build-up of soil borne diseases (HDC, 1991-1994). Since organic growers practice rotations problems are less likely to occur with the three main storage diseases.

Other fungi that may cause problems are *Fusarium* spp., *Penicillium* spp., *Rhizopus* spp., *Cylindrocarpon* spp. and *Geotrichum* spp. These are generally considered opportunists that develop as surface moulds or enter via tissues already invaded by other pathogens.

2.4.7.2. Growing for storage

Weather conditions during growth of the crop and harvesting affect likelihood of storage diseases developing. Also prolonged sunshine and reasonably high temperatures help produce high dry matter and sugar content which enhances good storage.

1) Avoid diseases. Practice crop rotations as this helps to avoid soil borne diseases such as *Phoma betae* (canker), *Botrytis cinerea* (grey mould rot) and *Streptomyces scabies.* Use disease free seed, which helps to avoid diseases such as *Phoma betae* which is seed borne and develops in long term storage.

2) Choose suitable varieties for storage. Characteristics to consider are, disease resistance (although there is very little information available), production of a low proportion of baby beetroot, and have adequate tops remaining at harvest if it is intended to lift by machine.

3) Plant the crop at suitable spacing: If a top pulling harvesting machine is to be used drilling must be in rows or narrow bands. This will avoid unnecessary damage at harvest. Elevator diggers can be used where top pullers are not available or a high density cropping pattern has been used.

Care should be taken at drilling to get an even crop, as this will make flail topping and harvesting by machine much easier.

2.4.7.3. Harvesting for storage

Beet for clamp storage should be lifted relatively late in the year when temperatures are low. Beet lifted too early when temperatures are warm will soon deteriorate and heat up.

Lift beetroot in a cool part of the day. They will soon heat up in store, producing three times as much heat as potatoes. Overheated beetroot are not suitable for cooking or processing.

Avoid harvesting in wet soil conditions to avoid too much soil sticking to the roots.

Frosted roots should not be put in store.

Avoid damage at harvesting and grading. Careful hand harvesting and grading in comparison to machine harvesting and grading reduces damage and disease entry. This in turn results in lower storage losses (HDC, 1990).

Baby beetroot (<40mm) do not store well. However, grading out baby beetroot by machine before storage is likely to increase damage to the crop and consequently storage diseases. (HDC, 1991-1994). Therefore, its sensible to lift at a time when the crop is at a suitable size for storing to avoid unnecessary grading.

The beetroot should be topped before going into store. Top pulling harvesters will top the crop and settings need to be positioned carefully. It is better to leave a few leaves on, which will whither in store rather than risk cutting into the crown. The crown must not be cut off or rotting will quickly develop.

Where an elevator digger is used, flail topping the crop before harvesting will aid lifting, but this is not easy with uneven crops.

2.4.7.4. Clamp storage and ambient air cooled storage

In the past conventional beetroot was considered a low value crop so that refrigerated storage was regarded as too costly. Consequently the use of various types of clamps has been well researched and published by workers such as Davies *et al.*, (1976) and Chrimes (1970). Although grown conventionally, these crops were not treated with fungicides during growth or subjected to postharvest treatments, and are therefore considered as relevant to organic beetroot storage. The information from these studies has been drawn together in ADAS booklet 2444 - Beetroot (1983) which gives details on the construction of suitable clamps, such as stack height and width, and methods using bulk boxes (see section 2.3.7 for further details). Storage methods have also been studied more recently in HDC funded work.

Beetroot store very successfully in clamps until March. Studies have shown that in a year when there was relatively little problem with storage diseases, no real benefit was gained by using cold storage or ambient air cooled barn storage over clamp storage up until March. Likewise the benefits of cold storage over ambient air cooled storage were not apparent in late April but may have been if trials been extended until May (HDC, 1990).

2.4.7.5. Refrigerated storage

Beetroot can be kept in cool storage up until July but it is only worthwhile contemplating refrigerated storage if it is planned to market after April. Clamp and ambient air cooled storage are adequate up until this time especially in a dry year when there is likely to be little storage disease about. In a wet year, when disease pressure may be higher, refrigeration may be of more benefit for shorter term storage. Machine harvested crops which tend to suffer more damage than hand harvested crops may also store better in refrigerated storage (HDC, 1991-1994).

For prolonged storage optimum refrigeration conditions are 3°C at a relative humidity of 95-98%. At cooler temperatures, such as 1°C, storage life is reduced to about 16 weeks.

As the crop has a relatively high respiration rate, care should be taken to vent carbon dioxide from the store (3-4 air changes per day) to avoid it building up to unsafe levels for staff.

2.4.8. Pumpkins and winter squashes

2.4.8.1. Introduction

All pumpkins are in fact squashes and belong to the genus *Cucurbita*. The term pumpkin is used for small round orange squashes or for the large orange field type. Winter squash, on the other hand, is a much more general term applied to squashes that have been selected for their keeping quality. They have hard skins, a relatively dry flesh when mature, and come in a wide array of shapes colours and sizes. Pumpkins do not usually store for very long and need to be cleared by Christmas. Winter squashes can usually store longer, up until Easter and beyond, depending on the variety.

2.4.8.2. Current practice and problems

Pumpkins and winter squashes do not usually suffer from disease problems (Tolhurst, 1997, pers. comm.), therefore it is not envisaged that storage of organic squashes should be any more problematic than conventional. A major problem with pumpkins and squashes is customer acceptance. Pumpkins are a very under rated crop in the UK. Many people equate them with marrows, which have a reputation for being an oversized, bland vegetable, requiring cooking with something else.

Over the past few years as the UK has developed more adventurous eating habits, there has been an increasing interest in pumpkins and squashes. Due to their popularity in America there are a vast array of varieties available with different textures and flavours. Since many varieties store easily without refrigeration, they are a good crop for organic growers to consider, especially if they are running a box scheme where customers are more likely to appreciate unusual vegetables. It is a good idea to provide customers with recipes and information on nutritional value, despite willingness to try new things, many people still do not know how to use them.

2.4.8.3. Storage

As for most crops there is no point in attempting to store damaged or under ripe pumpkins or squashes. The fruit should be examined carefully before going into the store and those of poor quality disposed. For maximum storage life, the fruit should be allowed to ripen and reach its full colour on the vine. ‘Handles’ should be left on and care taken not to knock them off or rots can enter the wound left behind. The fruit is best left out in the field for as long as possible, but susceptibility to chilling injury means they must be brought in for storage before the first frosts.

It is vital that pumpkins and winter squashes are properly cured. This hardens and seals off the skin, preventing moisture from escaping and organisms which cause rot from entering. In warm sunny climates curing can take place in the field. The fruit can be cut from the vines, leaves and debris removed, wind rowed and left in the sun. In cooler, wet climates curing may need to be done inside. Ideally curing should be carried out at temperatures between 20-25°C for about one week. If a glasshouse is available, the fruit can be laid out to cure. It is important to open the vents as high humidity must be avoided. For this reason polythene tunnels are not so suitable. If equipment for onion curing is available this can also be used for curing pumpkins and squashes. (Winterbottom, 1997, pers. comm.)

Ideally pumpkins and winter squashes should be stored at 10°C and at low humidity (50-75% RH). The temperature should not fall below 10°C as they are susceptible to chilling injury. (Winterbottom, 1997, pers. comm.).The exact temperature which induces chilling injury depends upon variety and the length of time the crop is at a particular temperature. Some varieties of Kabboca and Gem can withstand some freezing so these varieties are better than others for storage overwinter (Tolhurst, 1997, pers. comm.). However, the occurrence of chilling injury can be hard to predict so it is important to keep temperatures at 10ºC or just above if at all possible. It is not usually worth trying to use a cool store, few other crops will store at this temperature and humidity.

Pumpkins can easily be stored in a frost free barn or shed. A dry wooden building is best. Ideally they should be laid out on shelves with space around them so that the air circulates and humidity does not build up. Trays or crates which hold around 20-25 kg work well, bulk bins on the other hand have been found to cause rots, probably because they don't allow enough air circulation (Tolhurst, 1997, pers. comm.). The expected storage life is very dependent on variety. For example, Tindal (1983) reports that 'Butternut' stores for 50 days at 10-16ºC and 60% RH while 'Hubbard' stored for 180 days under the same conditions. Most other reports of storage are at temperatures over a similar range but quote higher optimum relative humidities in the region of 70 - 75% (Thompson, 1996).

2.4.8.4. Varieties for storage

It is vital to choose the correct varieties for storage as the expected storage life varies greatly from one variety to another. It is best to get advice from your seed supplier. A.L. Tozer Ltd supply a wide range of pumpkin and winter squash varieties and have experience with these crops. They can also provide a leaflet on how to grow the crop and have published a small recipe booklet. Other suppliers include Clause (UK) Ltd, S& G (Sandoz Seeds), Nickerson-Zwaan, Steve Howe Seeds Ltd. Most only stock a small range of pumpkins rather than winter squashes.

Types which can store until Easter are:

- **Kabocha**
- **Gem**
- **Crown Prince**

Acorn and **butternut** types on the other hand do not store as long and should be cleared before Christmas.

2.5. COSTS OF VEGETABLE STORAGE AND CASE STUDIES

2.5.1. Introduction

The costs of storage may be divided into:

- capital (or structure) costs for the building and equipment; this is divided over the expected life of the building, say 10 years and called depreciation.
- interest on the capital cost of the building, assuming this money is borrowed.
- interest on the crop stored due to the delay in its selling time.
- loss of weight of crop in storage, due to drying, disease and rotting.
- annual running costs of operating the store. e.g. electricity or repair costs.

See Table 17 for cost analysis

Table 17 An example of the annual cost of potato storage (800 tonnes ambient store)

	£/tonne
Depreciation on capital (10 years)	13.0
Interest (6% on initial value)[a]	6.5
Interest on potatoes stored for 5 months 8%[b]	10.0
Loss due to shrinkage, disease, rotting 10%[c]	30.0
Handling and drying costs, maintenance of store	2.0
Total	**61.5**

[a] this represents $^5/_8$ th of the expected average annual interest rate over the life of the asset.(10% assumed) In budgeting it is the average annual interest charge over the life of the capital item that is included. A common convention is to allow half the rate of interest on the initial capital. Where the buildings or equipment have some value at the end of the depreciation period this tends to underestimate the costs, therefore an amount exceeding half the interest rate should be charged, approximately $^5/_8$ th (Barnard & Nix, 1979).

[b] interest on the value of the stored crop is charged because the crop could have been sold and money used elsewhere or to reduce overdraft.

[c] estimates of losses vary from 6% to 15% depending on condition of potatoes going into the store, the type of store, and the length of storage (Callis, 1970).

2.5.2. Case Studies

In the following section a range of storage techniques suitable for root and vegetable growers are listed with details of their capital and annual storage costs . A comparison of the annual costs is shown in Table 18. (the Case Studies do not show interest on crops stored or loss of weight since these vary between different crops). Many of these are based on real life examples and so represent case studies of current practices. A short section detailing possible grants for storage follows this.

It should be noted that storage costs vary enormously according to levels of insulation, length of storage and external air temperatures. The costs listed should therefore only be taken as a guide. It is important for individual farmers to prepare or have costings prepared for their own case.

Considerable savings can be made by-do-it yourself work for some types of buildings using farm staff, especially if done in a slack period (labour costs of new buildings quoted below amount to 30-40 % of overall costs). Savings can also be made by the use of second hand materials where these are readily available. Much farm building work includes conversion or alteration to existing buildings.

Table 18 Annual costs of storage (per tonne)

	1	2	3	4	5	6	7	8	9
COSTS (£/t)	Field storage carrots	Outdoor clamp	Dickie Pie	Clamp in a barn	Refrigerated container	Small cold store	Small ambient store	Large cold store	Large ambient store
Building Depreciation				5.75	1.3	2	13.96	10.6	13
Interest on capital				3.45	0.78	0.6	8.37	6.4	7.8
Electricity			1.5		2.12	2.66	1.5	10	1.6
Repairs/ maintenance				0.87	1	0.2	2.5	3.33	1.95
Boxes									
Straw	21	1.5	2.25	1.5					
Polythene sheeting	13	0.27	0.2						
Ducting fans			2.7						
Earthing up		0.5	0.5						
TOTAL COST £/TONNE	**34**	**2**	**7**	**12**			**26**	**30**	**24**
Cost £ /pallet					5.2	4.46			
Cost £/m³ (refrigerated stores only)					29	27		6	

Details of costed case studies as follows:

1. Field storage of carrots
2. A simple outdoor clamp suitable for potatoes and onions
3. A ventilated clamp
4. Storage barn/shed, including Dutch barn
5. Refrigerated storage container, or lorry back
6. Small cold /refrigerated store suitable for 30-50 pallets/bins
7. Small ambient air cooled store suitable for 100 tonnes of potatoes
8. Larger cold /refrigerated store suitable for 300-400 bins
9. Larger ambient air cooled store suitable for 500 tonnes of potatoes, and onions.

1) Field storage of carrots

This can be done by simply ridging up, however, more effective storage is obtained by the use of straw and plastic

<u>Annual storage costs</u>

	£/hectare (acre)	£/tonne
i) Ridging up	20-31 (10)	0.89
ii)Straw and plastic:		
Straw (40 tonnes)	600 (243)	
Black plastic does not include cost of disposing of plastic	371 (150)	
Total (yield 28t/ha)	**971 (393)**	**34**

A product is being developed from recycled paper, which in the future may replace plastic, it is likely to be a similar cost to plastic (Rickard, 1997 pers. comm.).

- Use of straw varies between 30-60t/ha. Overall average 40t/ha.

The cost of chopping and incorporating the straw into the soil can be considerable, varying from £80-250/ha depending on the number and type of cultivations (HDC, 1991/92).

2) Simple outdoor clamp

Clamps usually consist of a heaped crop covered with plastic and straw to insulate against cold weather. Clamps can be constructed outside or alternatively inside a building.

<u>Annual storage cost (200 tonnes potatoes)</u>

	£	£/tonne
Straw (20 tonnes straw)	300	
Polythene sheeting(one 18m x 25m roll)	54	
Earthing up	100	
Total	**454**	**2.27**

(Callis, 1970)

Clamp 8m wide x 50m long

Straw: 100 kg per tonne potatoes (the amount required will vary with size of bales used)

Earthing up JCB for 8hrs

These figures do not include the cost of labour and machinery for loading and unloading the crop from the clamp. To allow mechanical unloading, clamps must be on hard ground or on a concrete base.

3) Ventilated clamp (Dickie pie) 200 tonnes potatoes

Ordinary clamp with the addition of ducts for ventilation, fans may be used to circulate air through the clamp

Annual storage cost

	£	£/tonne
Straw (30 tonnes straw - 150kg/t)	450	
Polythene sheeting	40	
Ducting/fans*	540	
Electricity/fuel (£1.5/t)	300	
Total	**1330**	**6.65**

*Small low volume fan £200, ducting £12.5/t both depreciated over 5 yrs (Record Sales Ltd, 1997).

4) Storage barn/shed

Many farms have an existing barn which can be used for a variety of purposes; from temporary storage of harvested produce through to longer storage over winter of crops such as, pumpkins and winter squashes. Clamps can be constructed under these barns for potatoes, onions, beetroot, cabbage etc.

Capital costs (new buildings)

	Gross costs (£/m^2)	
	200m^2	**400m^2**
General purpose building, 4.5 m to eaves fully enclosed concrete blockwork walls sheeted above:		
- insulated	185	159
- without insulation	166	142
Dutch barn, 4.8 m to eaves, side sheeting on three sides	99	85
Storage shed, sheeted walls, 4.8 m eaves	115	95
Pole barn, open sided	43	40

(SAC, 1997)

The maintenance and repair of these stores is relatively low (1-3% of capital cost), depending on their age. They would include costs of repairing and renewing roofing and guttering etc.

Annual costs for a 200t clamp within a storage shed (size 10m x 10m)

	£	£/tonne
Depreciation on building (10yrs)	1150	
Interest on capital (6%)	690	
Straw	300	
Repairs and maintenance	173	
Total	**2313**	**12**

Add £4-5/tonne for fans and ducts to ventilate the stored crop.

5) Refrigerated storage container, or lorry back

The prices listed below are all for second hand refrigerated ship or lorry containers which have been fully refurbished and come with a guarantee.

Capital costs

*Size length	Floor area	Store capacity	Temperature	Price(£)
10-15 feet	$10.4m^2$	$27m^3$	3-5º	1950
10-15 feet	$10.4m^2$	$27m^3$	0º	2250
18-24 feet	$18.2m^2$	$47m^3$	0º	2250-2950
40 feet	$34.0m^2$	$88m^3$	0º	3000+

*Size; all containers are 8 feet high and 8 feet wide. All refrigerated containers work most efficiently when 60-75% full of produce.

Containers have electric motors ranging from 2-10 HP (1.4-7 kW) Larger motors will have the capacity to cool quicker but will be more expensive. They will need to be connected to the mains electricity supply. If wanted to run independent of the mains add £500 for a diesel engine to generate the power.

The prices quoted are from Refrigerated Storage and containers Ltd. March 1997. The cheapest time to buy containers is in January/February, if bought in May/June add 30% to above prices.

Electricity running costs

These will vary with size of motor, throughput of vegetables, external temperatures and how often the container is opened.

Average electricity costs are likely to be between £1-3/day

Total annual costs (10-15 feet container)

	£	£/pallet	£/ m³
Depreciation over 10 years	195		
Interest on capital (6%)	117		
Electricity £1.5/day (30 weeks)	318		
Repair costs/service	150		
Annual running costs	**780**	**5.2**	**29**

Assuming this store is used to store 5 pallets of produce/week for 30 weeks = 150 pallets, this works out at £5.2/pallet. (This could be £5.2/tonne, however, this will vary with the type of produce being stored).

6) Small cold/refrigerated store suitable for 30-50 pallets/bins

These costs are based on modifying an existing building, including insulation of walls and roof installation of cooling system etc.

Size of building: 6m wide, 12m long and 3.5 m high

Floor area: 72m² Storage capacity: 252m³

Capital costs

	£
Boxes and door	6000
Equipment/insulation	8500
Site preparation	500
Total capital costs	**15000**

Total annual costs

	£	£/pallet	£/m³ storage space
Depreciation (10yrs)	1500		
Interest on capital (6%)	900		
Electricity	4000		
Repairs and maintenance	300		
Annual running costs	**6700**	**4.46**	**26.58**

(Watson, pers. comm. 1996)

This particular producer has an annual turnover (sales) of £400,000, therefore annual storage costs represent 2% of turnover, or on 50 pallets/week for 30 weeks (approx. 1500 pallets) = approx. £4.46/pallet.

7) Small ambient air cooling store suitable for 100 tonne of potatoes in boxes

This case study is based on modifying an existing farm building; insulating it, and installing a ventilation system, louvres, on floor ducts and an electrical control system.

Size of building: 13.6m x 7.36m

Floor area: 100m²

Capital costs

	£	£/tonne
Labour	3894	
Insulation foam	645	
Fans and ducts, vents	2858	
Boxes	4700	
Other materials	1391	
Electrical equipment	467	
Total capital cost	**13955**	**140**

Total annual costs

	£	£/tonne
Depreciation on capital(10yrs)	1396	
Interest on capital (6%)	837	
Electricity (£1.5/t)	150	
Repairs	250	
Total annual costs	**2633**	**26**

(Pringal, pers. comm. 1997)

8)Larger cold/refrigerated store suitable for 300-400 bins

This case study is also based on the modification of an existing building including insulating, and installing cooling equipment, a good sealing door and storage boxes.

Size of building: 13m wide, 30m long and 4m high

Floor area: 390m² Storage capacity: 1560m³ , 300-400 1 tonne boxes

Capital costs

	£	£/tonne/box (300)
Insulation(spray foam)	6000	
Cooling equipment	10500	
Door	1000	
300 Boxes	15000	
Total capital cost	**32000**	**106**

Total annual costs

	£	£/tonne/box	£/per m^3
Depreciation(10years)	3200		
Interest on capital (6%)	1920		
Barn operation	1000		
Electricity	3000		
Total annual cost	**9120**	**30**	**5.85**

(Watson, pers comm 1996)

9) Larger ambient air cooled store suitable for 800 tonnes of potatoes, and onions.

This is the price for a new building (bulk storage)

Size of building: 15m wide, 40m long, 6.1m high to the eaves

Floor area: 600m²

Capital cost

	£	£/tonne
Fully framed building fully insulated with ACNV and recirculation fans	104,000	130

Total annual costs

	£	£/tonne
Depreciation over (10yrs)	10400	
Interest on capital(6%)	6240	
Electricity (£1.6 /tonne)	1280	
Repairs and maintenance	1560	
Total annual cost	**19480**	**24**

(SAC, 1997)

2.5.3. Grants for Storage

There are now no general grant schemes for farm buildings which could include storage. The grants that are available are for certain 'less developed regions' of the country and are more likely to be available for marketing groups than individual farms.

Grants available for Buildings

Assistance to agriculture and rural areas, in the form of grants, is available from a variety of sources. This section summarises the main sources of aid for capital items. Conditions for aid vary and can be complex and it is essential to refer to the agency for full details before embarking on any scheme.

General Farm Grants

The main avenue for general farm grants was the Farm and Conservation Grant Scheme. However, the scheme has been closed since February 1996.

There are now no national schemes for buildings grants covering the UK, instead there are a number of schemes from the European Community (EC) for certain sectors or regions which are less well equipped to benefit from the potential of the single market. Similar schemes are available from local enterprise councils/development bodies for areas such as the Highlands and Islands in Scotland.

Objective 1

Grants are available in so called areas of lagging development, such as the Highlands and Islands of Scotland and Ireland and Merseyside.

Objective 5B funding for Rural Areas

In an effort to encourage sustainable revitalisation of the rural economy, the European Community (EC) has designated a number of areas in the UK for financial support from the three main structural funds - the European Regional Development Fund, the European Social Fund and the European Guidance and Guarantee Fund.

In England the areas are: part of East Anglia, parts of Lincolnshire, most of Shropshire, some areas of Hereford and Worcester, the Northern Uplands, parts of the South West and the Staffordshire and the Derbyshire Peak District. Many parts in Scotland (Dumfries and Galloway, the Scottish Borders, North and West Grampian, Upper Tayside and Rural Central Scotland) and Rural Wales are also covered by the scheme.

MAFF is working in partnership with government bodies, private sector organisations and individuals to revitalise the rural economy. A wide range of activities will be considered for Business Development and Employment, Marketing of Speciality Foods and Farm Diversification, which could include storage.

Standard costs are issued by MAFF, and the Scottish (SCOAFD), Welsh (WOAD) and Northern Ireland (DANI) Agricultural Departments. They are designed to help claimants for capital grants who organise building themselves and reflect the cost of using farm or casual labour without allowing for any profit element. Contact MAFF Land Use and Rural Economy Division for further information.

Objective 1 and 5b funding is likely to be severely restricted after 1999 as part of the Agenda 2000 proposals, although nothing is yet definite.

2.5.3. Conclusions

Although it is necessary for the individual farmer to cost and assess his own storage situation, it is possible to draw some general conclusions which may provide useful guidance.

The costs of storing organic produce is very similar to that of storing conventional produce, in terms of structure and operating costs. Where chemicals are used in conventional storage this will result in initial lower costs for organic storage. However, increased disease and rotting of organic produce will lead to a larger % grade-out at time of sale and this is likely to mean that, overall, the cost of organic storage is higher than conventional.

Field storage, clamps, (indoor and outdoor), adapted buildings using natural ambient convective ventilation all involve low fixed capital investment and so allow flexibility in decisions on whether to store or to sell off the field. They result in low annual running costs per tonne and are thus suitable for use with crops such as potatoes and onions etc. Such stores can benefit from the use of forced draught ambient air by the use of ducts and fans for an addition of £4-5/t.

Highly insulated bulk stores with forced draught ventilation can provide relatively cheap and better storage, especially for larger tonnage's. However, greater price premiums must be achieved to give a satisfactory return on the amount of capital invested.

Refrigeration and box storage involve increased costs. There are clear economic advantages to using transit cold storage to remove field heat and to keep produce in good condition and the use of a refrigerated container offers a reasonably low-cost place to begin. Boxes have an initially high outlay (£48 per tonne box) but offer the convenience of easier handling and the ability to store lots separately which may justify their use.

Long term cold storage (costing £30-40/t) does require that a premium is obtained from selling produce in April and May to make it profitable. Economies of scale exist for larger stores which in the case of many small producers, points the way towards co-operative ventures in storage. The present wide distribution of organic growers would make this difficult at this time.

There are a wide range of storage systems. If the best alternatives are chosen, storage could be made more profitable. Improvements in production and marketing could also have a great effect on the profitability of storage. For example, the establishment of a good box scheme or links with retailers, could make it feasible to invest in better storage.

2.6. ECONOMIC ANALYSIS AND MARKET PRICES OF ORGANIC VEGETABLES

2.6.1. Introduction

One of the main aims of storage is to improve the financial returns which can be made from marketing a crop, for example delaying the selling of produce until a time when the price is higher. Against this must be set the actual costs of storage. Storage can only be profitable if the returns exceed the costs. It is also an important way of reducing the uncertainty involved in marketing crops at harvest time, thus enabling producers to reduce potential income variation from year to year, which is characteristic of crop growing.

2.6.2. Literature reviewed and sources of information

The literature on the economics of storage is small. Basic farm management text books, (e.g. Barnard & Nix, 1979) provide some background on investment decisions and techniques. Guide costs for new buildings are provided by most of the annually published Farm Management handbooks (Nix, Wye College, ABC, SAC). More detailed costings are provided by the Scottish Agricultural Colleges, (SAC Building design unit, annually) and representatives of companies (Farm Electric, 1997). Much of the other information contained in this study has been gained by conversations with growers, farmers and manufacturers of storage equipment.

2.6.3. Vegetable Prices

Prices of vegetable produce are subject to seasonal variations within the year and fluctuations from year to year. The prices vary with seasonal changes in demand e.g. more Brussels Sprouts are consumed around Christmas, and with longer term changes in eating habits. Supply probably has a more major short term influence on price though, and fluctuations in supply are due to such factors as the weather, and level of imports. In some cases prices are affected by the level of institutional (government, EC) support for the market, however, this is more so for other agricultural sectors than for vegetables.

Prices will vary according to market outlet and quality requirements. The highest prices for the grower are obtained from direct marketing (farm shops and box schemes). Of course these forms of marketing have added labour, packaging and transport costs which will need to be taken into consideration. Packer prices are often higher than wholesale prices, although a large % grade-out at the packhouse may lead to lower total financial returns. Processing prices are normally lower than wholesale prices.

2.6.3.1. Seasonal variations

The usual trend is that prices are at their lowest following harvest and then gradually rise to a peak just prior to the next harvest. This trend can be seen by examining the trend of prices over a number of years. The graphs in Fig 13 and 14 show the 5 year average wholesale prices for conventional carrots and onions, two commonly stored crops. These clearly reflect the above trend with prices being lowest in October/November and rising to their peak in June. Other crops commonly follow this general trend.

There is likely to be a case, for example one year in three, when prices do not rise as predicted and in that year storage will not be profitable.

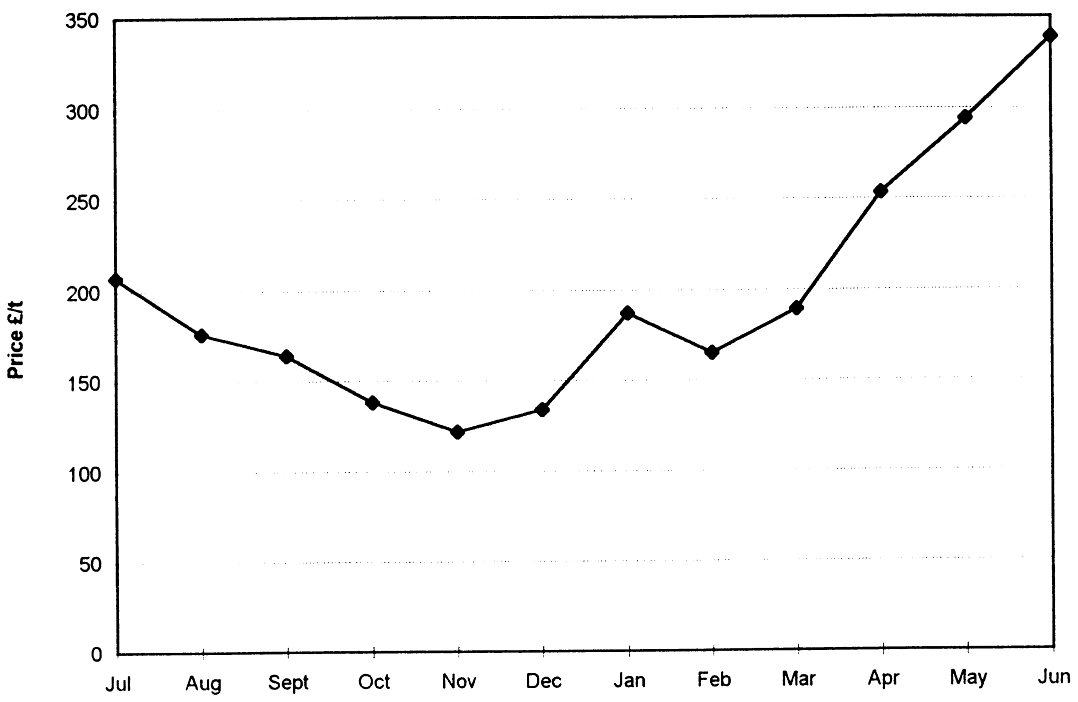
2.6.3.2. Organic prices

The quantity of statistics on organic prices is presently very small and sketchy. Table 19 and Figure 15 compare a sample of storable conventional and organic wholesale vegetable prices in 1995/96, in that year organic prices were on average 167% higher than conventional prices. The difference ranges from 77-348% higher. Figure 16 compares the organic and conventional prices for potatoes and demonstrates some of the differences through one season. Producers selling through a box scheme usually aim to sell at conventional supermarket retail prices, or 50% above organic wholesale prices (Ryton Enterprises, 1997) Information was not available on packer or processing prices the later is a market which is not presently well developed.

There is some anecdotal evidence that organic prices are less volatile than conventional prices due to the fact that domestic production, for example in the case of vegetables, supplies only a small proportion of the UK market, the remainder being made up from imports. Thus the price of imports would appear to have a large influence on UK prices. Unlike conventional prices which can fluctuate daily, organic vegetable prices can stay relatively stable over a period of 2-3 months see Figs. 17-20.

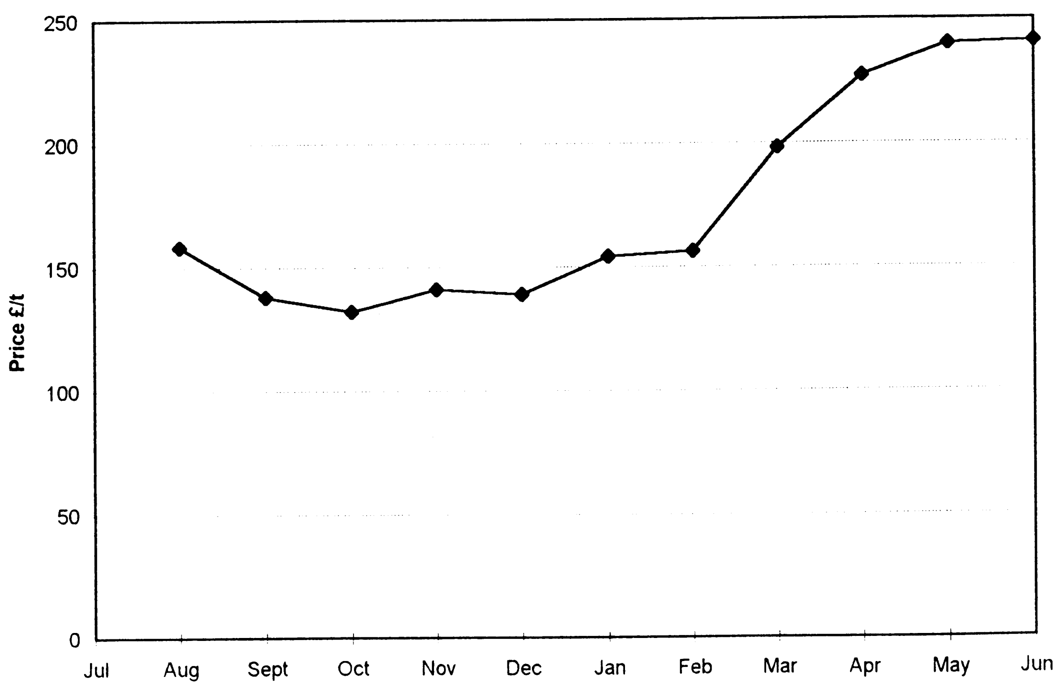
For the last two seasons 1995-96 and 1996-97, for many storable products, (potatoes, onions, swedes, beetroot and carrots) higher wholesale prices were obtained in September than in May see Figs. 17-20. Beetroot in 1995-96 would be an exception to this, when prices rose to £520/tonne in March and April (Fig 21). In 1995-6 potato prices fell when too many organic producers tried to store poor grade potatoes (Figure 17). They would have been better to have sold when prices were high (due to drought) when the main crop was harvested. Unfortunately, new potatoes imported in February were of much better quality so prices collapsed. (Segger, 1997, pers. comm.) There was a similar situation with carrots in 1996/97 (Figure 18). Therefore it would appear that importation of early produce has a depressing effect on the market price.

Figure 13 Wholesale average price of carrots for the past 5 years (conventional)



Source of information: MAFF Monthly Fruit and Vegetable Prices Feb. 1997

Figure 14 Wholesale average price of onions for the past 5 years (conventional)



Source of information: MAFF Monthly Fruit and Vegetable Prices Feb. 1997

Table 19 Comparison of conventional and organic vegetables prices 1995-6

	Conventional	Organic	% difference
Carrot	277	637	130
Beetroot	172	425	147
Swede	161	378	135
Onions (dry bulb)	149	667	348
Potato*	196	346	77

All sources :wholesale prices except * conventional prices : Farmgate plus 20%

Sources: Conventional prices: MAFF, 1996

Organic: Organic Marketing Co Ltd

Figure 15 Comparison of conventional and organic vegetable prices 1995-96

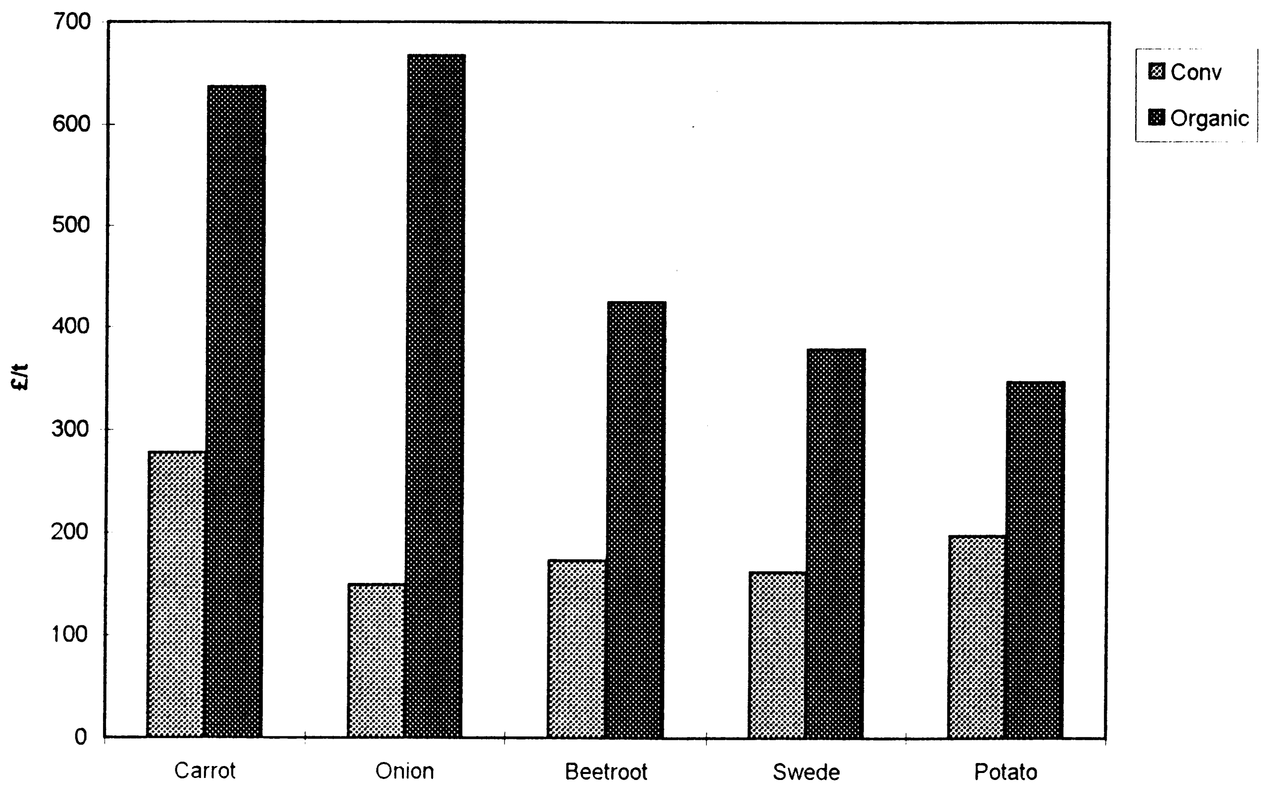
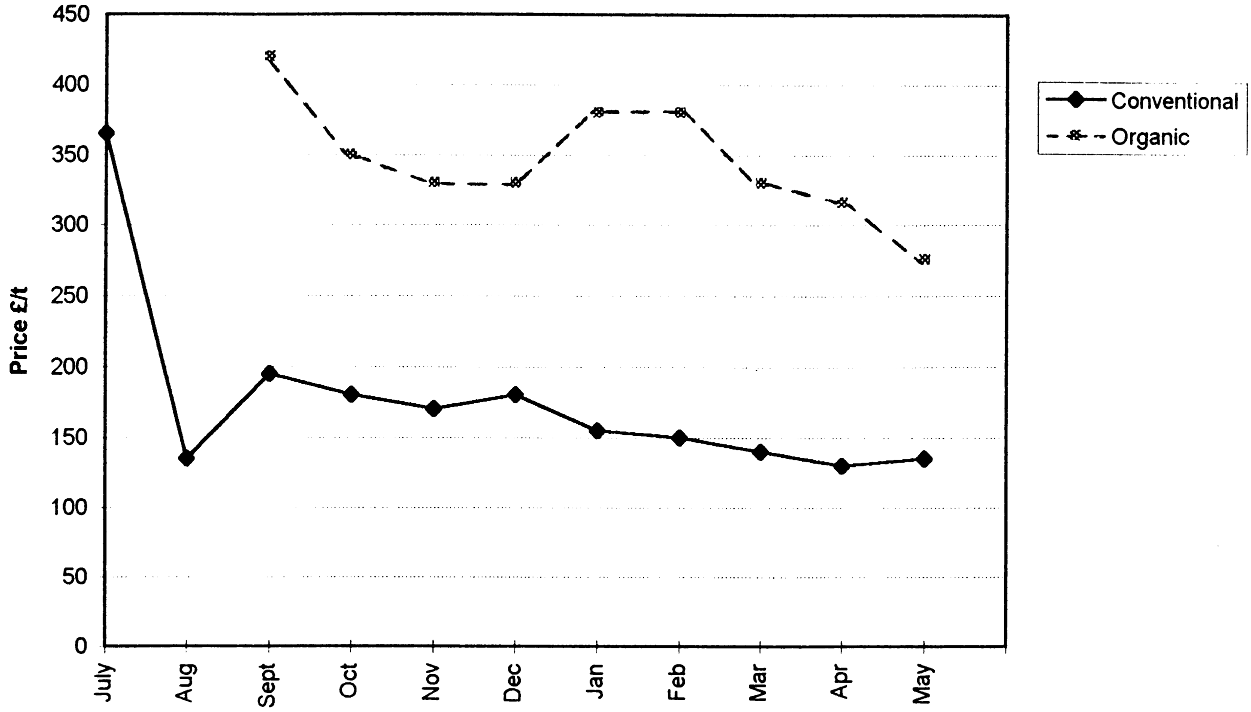
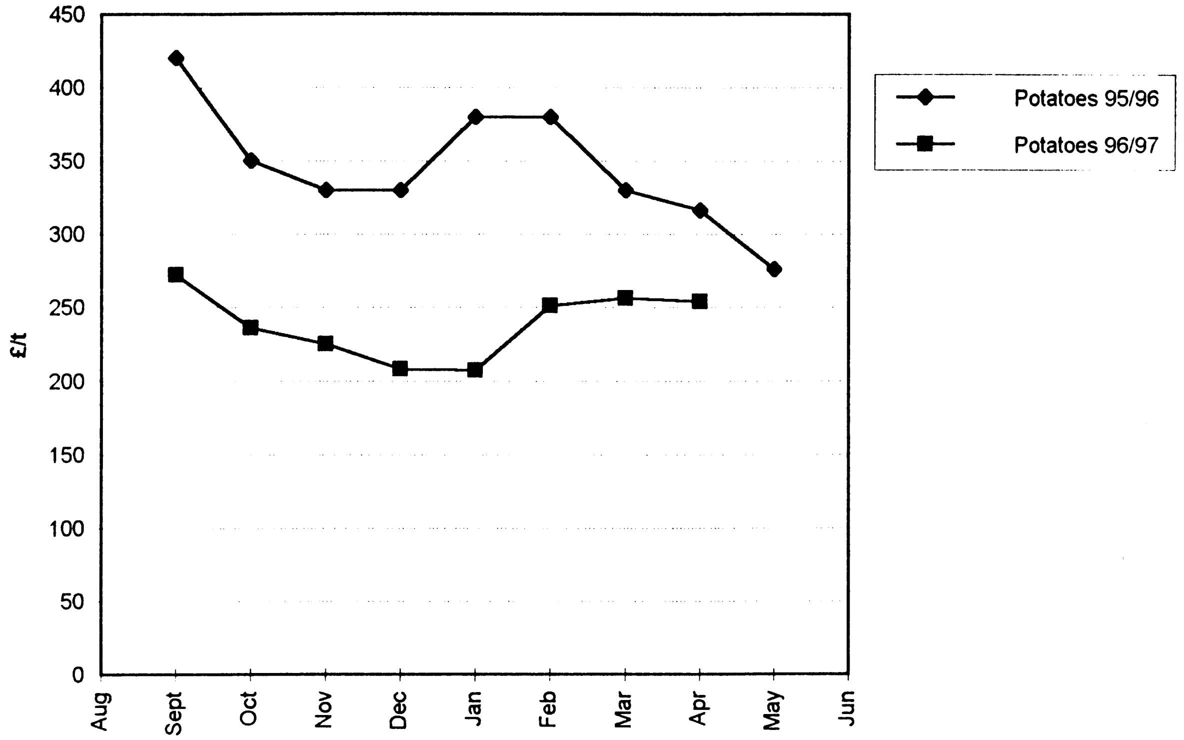


Figure 16 Comparison of conventional and organic potato prices 1995-6



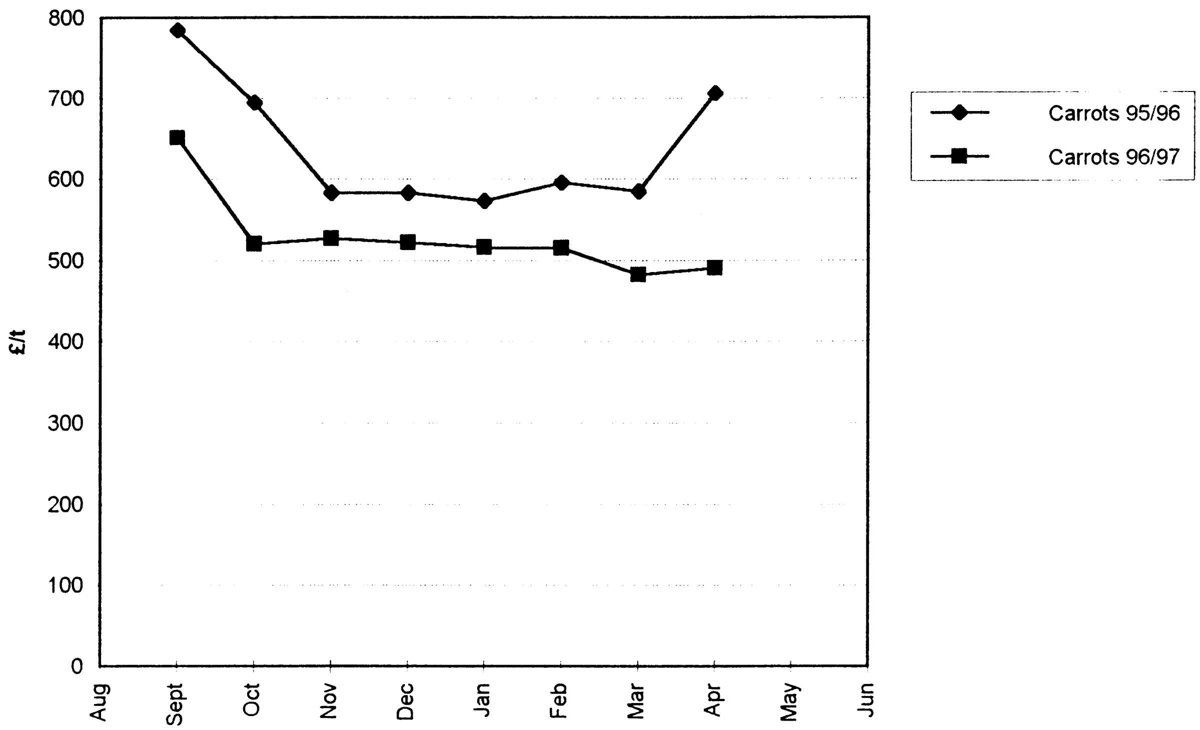
Source: Conventional-Farmers Weekly; Organic- Organic Marketing Company Ltd.

Figure 17 Wholesale organic potato prices 1995-97



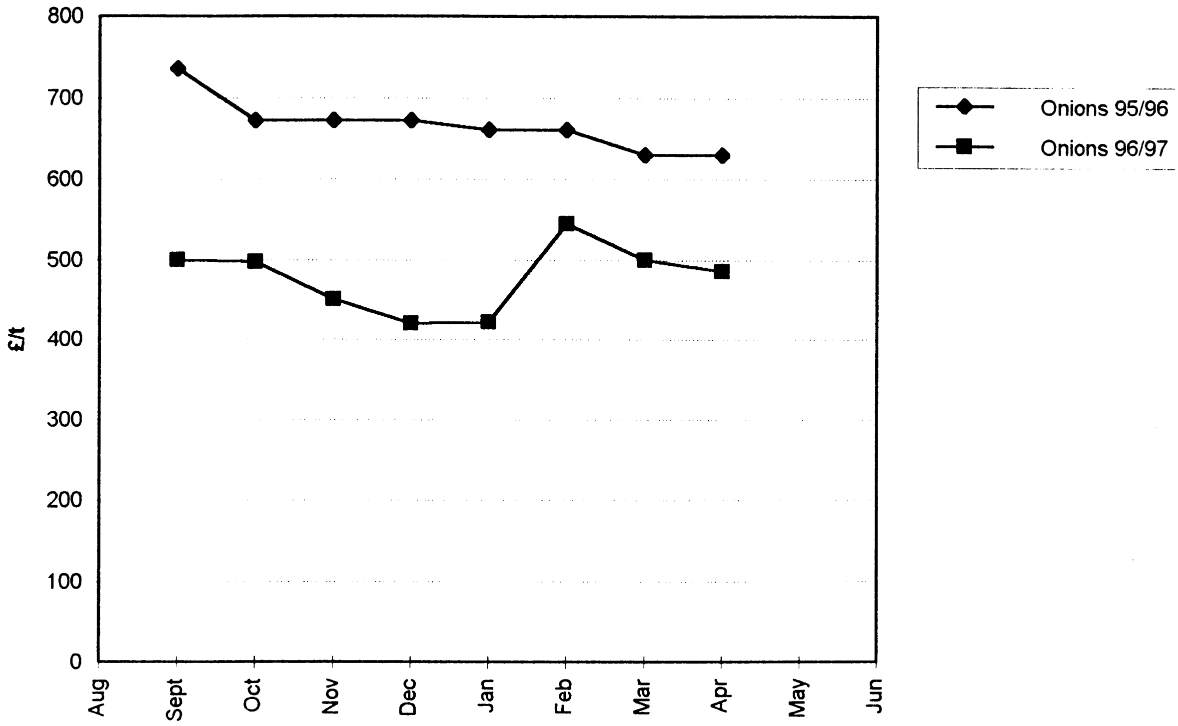
Source: Geoff Mutton, Organic Marketing Company

Figure 18 Wholesale organic carrot prices 1995-97



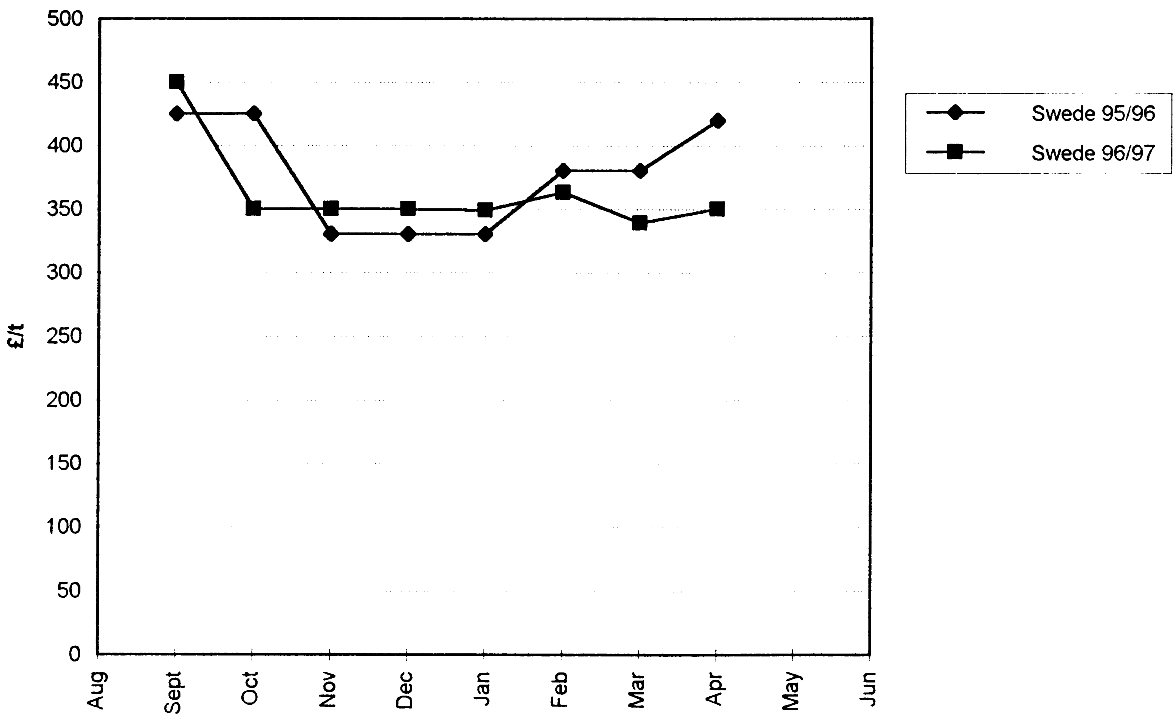
Source: Geoff Mutton, Organic Marketing Company

Figure 19 Wholesale organic onion prices 1995-97



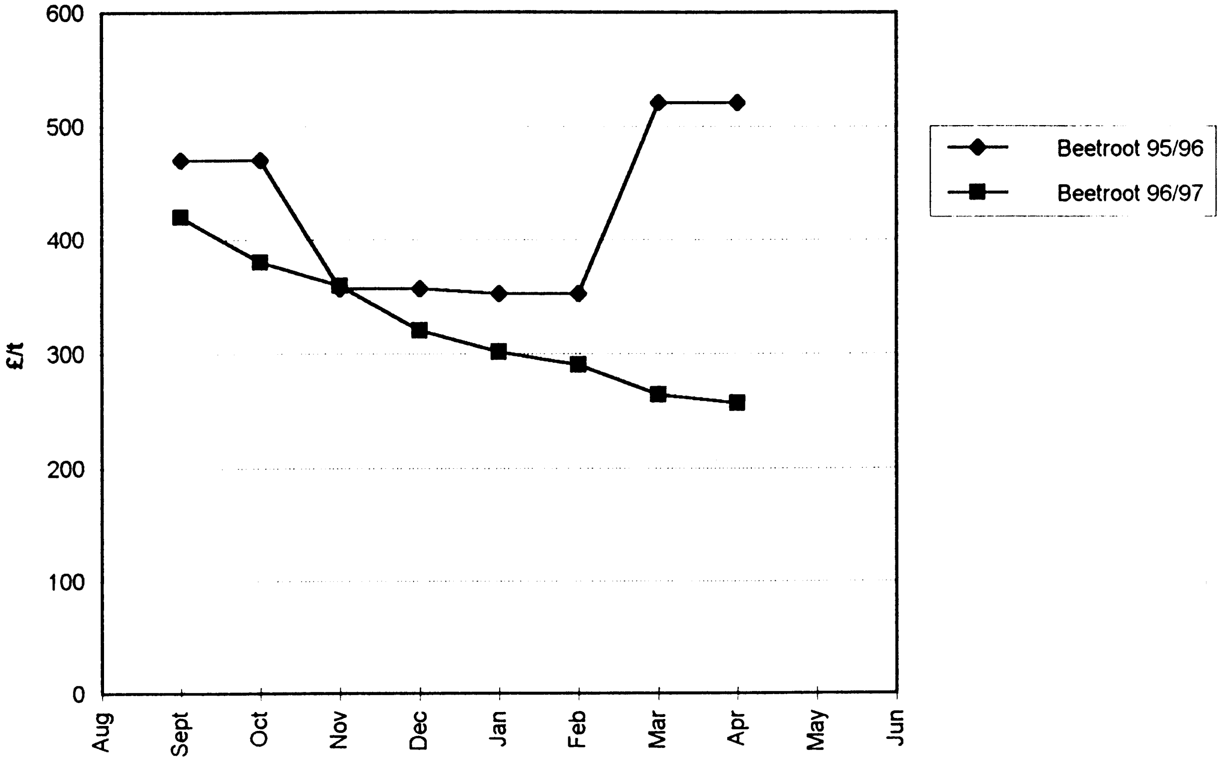
Source: Geoff Mutton, Organic Marketing Company

Figure 20 Wholesale organic swede prices 1995-97



Source: Geoff Mutton, Organic Marketing Company

Figure 21 Wholesale organic beetroot prices 1995-97



Source: Geoff Mutton, Organic Marketing Company

2.6.4. Increased returns from storage

These crops can be obtained in a variety of ways:

Timing. Long term storage of products whose price is low at harvest time. These are usually marketed from the store from January to June, when the prices are usually higher. The increase in price should rise sufficiently to cover the cost of storage.

Quality. Transient cold storage removes field heat and keeps the produce in good condition and results in higher prices being obtained for a better grade of produce and less waste being incurred.

Continuity. Continued supply to customers, which is very important for establishing and maintaining a market e.g. for a vegetable box marketing scheme.

2.6.4.1 Will storage pay?

In order to store some kind of investment in storage facilities is necessary the type depending on the length of storage and the quality of the market. Types of storage will range from simple clamps to more sophisticated refrigerated storage. Indications of the level of these costs is given in section 2.5 (Table 18) and in Tables 20 and 21.

In assessing storage two rather different aspects of an investment need to be examined. First is profitability - that is, the extent to which the extra income produced by the new building/ method of storage covers the original cost. The second is the financial feasibility - that is the ability to borrow and repay money required for the investment and the financial risks involved.

There are a number of techniques which can be used to assess whether investment in storage is economic, and to help assess some of the risk involved in making investments, and as such many of them are also capital investment appraisal techniques. These are described below and analysed using examples of organic prices and costs of storage.

Any decision making regarding whether to store or the length of storage involves a certain element of risk due to uncertainty of future prices. Access to past and probable future prices combined with the techniques ,such as described below, can be used to aid in decision making. Due to insufficient organic vegetable price information decisions on the timing of selling vegetables have not been addressed here, the principles of this are dealt with in detail by Bateman (1972).

Table 20 Comparison of storage methods annual costs/tonne

Clamps and ambient stores	£/t	Cold storage	£/pallet	£/m^3
Field storage of carrots	35	[3]Refrigerated storage container	5.2	29
Outdoor clamp	2	[4]Medium sized store	4.5	27
Dickie pie (and forced ventilation)	7	Large cold store		6
[6]Clamp within a barn	12		**£/t**	
[1]Small store (ambient air)	26	[5]Large cold store	30	
[2]Large ambient air store	24	Hire of cold store	40-50	

1. See Section 2.5 Case Study 7
2. See Section 2.5 Case Study 9
3. See Section 2.5 Case Study 5
4. See Section 2.5 Case Study 6
5. See Section 2.5 Case Study 8
6. See Section 2.5 Case Study 4

Table 21 Capital costs of storage/tonne

Potatoes*	£/t	Cold storage	£/t
[a]Small pole barn (10mx13m)	28	[a]Adding refrigeration to existing potato store (500t)	20-25
[a]Storage shed (sheeted walls)	75	[b]Refrigerated container	13
[a]Insulated bulk store - air cooling	139	[a]Cold store (300t)	291
[a]Insulated box store - air cooling	130	[c]Modifying existing store	106

* Although potatoes have been used other produce such as onions could be stored in these buildings

a SAC 1997

b See Section 2.5 Case Study 5 based on storing 150 pallets or tonnes p.a.

c See Section 2.5 Case Study 8

1) Partial Budgets

These are used to estimate the additional income to be gained (and costs saved) which can be weighed against the cost of any storage e.g. clamp or building. This can assist the producer in weighing up the pros and cons of the intended investment. Total B must exceed total A for storage to be economic (see Table 22).

Table 22 Estimating a partial budget for vegetable storage

Costs	**Extra income to be gained**
Capital cost of building (usually spread over the anticipated life of the building) Cost of finance (interest on capital) Cost of finance from delayed sale of markets crop Running costs of store(electricity, repairs) Waste/ losses in store	Higher prices from a) long term increases in price b) better quality (grade) of product c) continued supply of premium
Income foregone	**Costs saved**
Reduced weight due to respiration and disease losses	Less waste e.g. from transient storage Tax allowances to claim.
Total A	**Total B**

2) Break-even analysis

This is an assessment of the break-even point (between profit and loss) at which it would be profitable to store, based on average costs and expected prices. Expected prices would be based on averages of good and bad years, and would involve estimating probable future prices. In terms of storage this would involve calculating the costs of storage per tonne and from this calculating the price increase required to cover this cost.

Case study of organic onions

From section 2.5, Table 18 and Case Study 4 of a clamp store in a barn it is possible to estimate that storage charges for a 5 month period would be approximately £12/tonne. (This figure does not include cost of interest on the stored crop or loss due to shrinkage, disease and rotting) In order to achieve the break-even point, the price of onions would have to rise by £12. Examining the prices obtained for 1995/96 and 1996/7, assuming storage from November to March.

Onion Prices(£)	November	March	Price rise (£)
1995/96	680	650	-30
1996/97	450	500	50

Based on these prices the break-even point would have been passed in 1996/7 but not in 1995/96. On the average of these two years, a £10 increase, the break-even point would also not have been reached. In both years higher prices could have been obtained from selling onions in September, if a market was available.

3) Rate of return

This can be used to calculate the likely return on the extra capital invested in storage, which can then be compared with rates calculated from other investments, such as irrigation or glasshouses. This is discovered by dividing the extra profit before interest by the extra capital required and multiplying by 100.

With regard to depreciating assets the capital is either the total initial sum required or the average capital invested during the life of the project, which takes account of the depreciating asset.

The draw back of these methods is that it does not take account of returns of money over a number of years or the value of these returns in present day values. More sophisticated are 'discounted cash flow' techniques. These are essentially budgets which take account of different costs and returns between years of a project, and allows flows of money in the near future to be weighed more heavily than those in the far future. This could be useful to compare different costs of large capital projects such as comparing a large ambient store with a refrigerated one, or different types of grain store. An example of how this is calculated can be found in Appendix 1 (section 5.5.5)

An alternative method, used here, is $^2/_3$ of the initial net capital as an amount midway between total initial capital and average capital requirements which gives an approximate estimate of discounted return (Barnard & Nix, 1979).

Taking the example of onion storage in 1995/96 and 1996/7, the average profit would be

	£
Price increase(t)	10
less cost of storage	8 (not including interest)
Extra profit/tonne	2

If we assume the grower stored 200 tonnes of onions, the total extra profit is £400 (200x £2). The net capital required was £11,500 x $^2/_3$ =£7659*

Rate of return = $\frac{400}{*7659}$ = 5%

Rates of return must exceed the cost of borrowings to show a profit (8%1995/96). The above rate of return does not do this.

4) Pay back

This measures the number of years needed for an investment to repay the initial capital, and is a useful 'rule of thumb' for comparing different investments.

From the above example of onion storage; It would be calculated by dividing the total capital cost by the additional profit created before charging depreciation.

Initial capital £11500
Adjusted extra profit £750 (£3.75/t)

Payback would be achieved in 15 years.
Payback within the life of the asset is important for feasibility, i.e. less than 10 years.

Table 23 Economic appraisal of vegetable storage techniques**

	In-door clamp(220t)			Ambient storage(100t)		
	Cost of Storage (£/t)	**Return on capital (%)**	**Payback (yrs)**	**Cost of storage (£/t)**	**Return on capital (%)**	**Payback (yrs)**
Onions	12	5	15	26	-10	-
Potatoes	12	57	2.4	26	16	8
Swedes	12	31	4.2	26	3	17
Average	**12**	**31**	**7**	**26**	**3**	**13**

* These figures are all based on wholesale vegetable prices for 1995-97 and for a storage period from November to March

Since beetroot is not widely stored, figures for the crop have not been included above. If they had been included the results would have considerably improved, see below.

	In-door clamp(220t)			Ambient storage(100t)		
	Cost of Storage (£/t)	**Return on capital (%)**	**Payback (years)**	**Cost of storage (£/t)**	**Return on capital (%)**	**Payback (years)**
Beetroot	12	149	0.98	26	62	3

** Cold storage is not analysed here, since the cost of storage is approximately £30/tonne (Section 2.5 Case Study 7) return on capital and payback would be lower than for ambient storage.

2.6.5. Conclusions

Long term storage. From the wholesale prices for 1995-97 for 4 storable vegetables there is evidence that prices for organic produce do rise enough to cover the cost of clamp storage within a barn, providing good rates of return and payback on original investment. However, they do not rise enough to cover the cost of long term ambient air and cold storage (see section 2.5, Table 18 for the approximate costs).

It is likely, that as the organic market becomes more established, with UK supplies increasing, that prices will more resemble the pattern of conventional prices falling by a greater amount at harvest and rising over the winter period, in that case other types of storage may become more economic.

Quality. Storage of vegetables in good quality by the use of refrigeration does have benefits in preventing losses. For potatoes loss in storage can be as high as 15% of the stored crop. This can be significantly reduced by use of refrigeration, which may be financially justified, considering the high value of organic produce. Such an analysis could be the basis for further research.

Continuity. The economic benefits of continuity are the ability to sell vegetables at premium (organic) prices throughout the winter season. These benefits are important but are sometimes difficult to quantify for the individual grower. However, for the grower selling through a box scheme it is easier to measure these benefits, which through storage, are the ability to sell at near retail prices throughout a longer period, this would be weighed against buying in the vegetables to supply the box scheme.

For further conclusions on the economics of specific storage methods see section 2.5.4.

3. STORAGE OF ORGANIC TOP FRUIT (APPLES AND PEARS)

3.1. SUMMARY

Growing pest and disease free organic top fruit in the UK climate is a challenge which very few growers have taken up. There is increasing interest from conventional growers who wish to convert to organic production, but there are many problems which need to be solved to reliably produce good quality organic crops.

The UK demand for organic apples and pears far outstrips domestic supply. Although demand is intense, storage of top fruit is required to avoid flooding the market at harvest time. All organic growers of top fruit either have their own stores or hire storage space. Refrigerated storage fulfils present requirements. It is sufficient to keep fruit in good condition for the few weeks needed. Most organic fruit has been sold off the farm by November.

If the market and supply does expand, then longer term storage will be required. Due to the high standards of quality demanded by the wholesale and supermarket trades, refrigerated storage can only sustain most varieties in suitable condition until December. Refrigerated storage for some varieties beyond December may remain an option for direct marketing schemes but fruit for the other markets will require controlled atmosphere storage.

The permitted use of controlled atmosphere storage needs to be considered by UKROFS. Controlled levels of oxygen, carbon dioxide and nitrogen are permiited in EU and IFOAM standards and there is the possibility that UKROFS will follow this precedent. The situation needs to be clarified by UKROFS and the other UK inspectorate bodies, before the UK supply develops.

Useful areas for research

Most of these research areas could be linked in with conventional research:

- Performance of rootstocks and varieties in organic systems.
  - Breeding varieties with pest and disease resistance, good culinary quality and storage characteristics.
  - Nutrient supply in organic orchards and its effects on storage disorders e.g. organic fertilizer applications, influence of understorey, mulching etc.
  - Control of scab (cultural methods and other organically acceptable methods).
  - Control of storage diseases e.g. cultural, biological control (pre-harvest and well as postharvest applications).
  - Forecasting the storage potential of organic crops.
  - Rapid detection of storage rot organisms and levels of infection
  - Storage life of different varieties together in refrigerated air stores.

- Controlled atmosphere storage of organic crops (optimum regimes and expected storage life without the use of fungicides and postharvest dips for physiological disorders.) The different growing conditions experienced by an organic crop may also affect storage regimes.
- Heat treatments to control physiological disorders and storage diseases.
- Collection of economic data to facilitate financial analysis of organic fruit production.

3.2 CURRENT PRACTICE AND PROBLEMS

The majority of organic top fruit growers either have or hire refrigerated storage. Although there is a great shortage of home produced fruit in the UK, storage is required for a few weeks to avoid oversupplying the market at harvest. The high value of the crop, combined with the high risk of not being able to sell all of the crop at harvest tends to justify the cost. Refrigerated storage will keep most varieties of apple until November/December. This is sufficient for the present market requirements. Some varieties of pear e.g. Conference retain a very firm texture in refrigerated storage and can keep until March/April but others such as Beurré Hardy will only store until December.

If the UK supply and market does expand, then more prolonged storage will be required. Refrigerated storage can not hold apples and many varieties of pears to the high standards of quality required by the wholesale and supermarket trade. Controlled atmosphere storage is the only technology available for this purpose at present. This method has not yet been considered by UKROFS, and is therefore not mentioned in the standards. The situation needs to be clarified, as it will affect the expansion of the UK organic fruit industry. Controlled levels of carbon dioxide, oxygen and nitrogen are permitted as storage aids in EU and IFOAM standards and manipulation of these gases are mentioned in the UKROFS processing standards. It is likely that UKROFS will at least consider permitting the use of controlled atmosphere storage (i.e. control of carbon dioxide, oxygen and nitrogen). A precedent has been set by the EU and IFOAM standards and the method is essentially in keeping with the spirit of the standards (Crofts, 1997, pers. comm.) Permitting the removal of ethylene from stores may be more problematic, as no precedent has been set.

Specific problems in storage of apples and pears are not regarded as a high priority by existing organic top fruit growers, probably because they only need to store the fruit for a short period of time. Technical problems such fruit becoming wet in certain areas of the store were mentioned by growers, but this is a problem associated with store design rather than the crop being organic. Other factors such as problems with establishing organic orchards, diseases such as scab (*Venturia ineaqualis*), crop nutrition, weed control and generally how to grow the crop in the first place are regarded as being more important. However, it is essential that storage requirements are considered during orchard design. Once planted and established rootstock and variety choice can not be changed for at least 20 years. Correct choice of variety is essential to storage success.

In order to make storage worthwhile the acreage of organic fruit needs to increase substantially. Part of this increase will come from conventional growers converting to organic production who already have good storage facilities including controlled atmosphere. The current review addresses the concerns of these growers and provides information for existing organic growers.

Growing fruit in the mild wet climate of the UK is a challenge. Many of the storage rots which infect the fruit prior to harvest are favoured by these conditions, as a result, fungal storage rots are likely to be a problem in organic fruit. Before the introduction of the benzimidazole fungicides in the early 1970's, fungal storage rots (the most common of which was due to *Gloeosporium* spp.), could cause up to 30% losses in the worse affected stores (Preece, 1967). Conventional growers now aim to have total losses due to rots below 2.5%. Physiological disorders such as superficial scald and bitter pit could also be potential problems. The extent of loss depends on several factors one of which is the nutritional status of the fruit, this is potentially harder to manipulate in organic orchards. However, understanding of the causes of both physiological disorders and fungal diseases has improved and new varieties which are less prone to these problems are available. Improved storage regimes and controlled atmosphere storage can reduce losses considerably.

3.3 THE ECONOMICS OF STORAGE

3.3.1 The market for organic fruit

There is a large and growing demand for organic fruit. Present estimates are that over 90% of organic fruit is imported. Of all the organic food sectors in the UK fruit is the least developed. Despite a strong consumer demand and high prices for organic fruit, there are only a handful of commercial apple and pear growers in the UK.

One of the stumbling blocks for organic fruit growers in the past has been the very high cosmetic standards demanded by the multiples, but there are now an increasing range of marketing opportunities available through direct marketing (Box schemes) and for processing. (Brenman, 1997, pers.comm.)

3.3.2. The economics of organic fruit growing

The growing of organic fruit represents an economic challenge, with high costs of establishment, variable yields and quality. There is a lack of published economic data to assess whether it is possible to make a profit from organic fruit growing, let alone storage on its own. This information still needs to be collected from the various retail markets in order to carry out economic analysis.

3.4. ORCHARD DESIGN AND METHODS TO PROMOTE STORAGE

3.4.1 Soil and site

It is vital to have a suitable site as this will determine the success of the orchard. Trees struggling on a poor soil will never thrive and will be prone to physiological disorders and disease. The soil should be tested to check it has the correct nutrient status, especially levels of calcium. Ideally choose a south facing slope, with wind protection. The soil should have a pH around neutral and be free draining but not prone to drought.

3.4.2 Planting

The site should be subsoiled, ploughed levelled, and cultivated to control weeds. A bastard fallow for the summer before planting to allow perennial weed control may be required on some sites. The soil should be carefully prepared for planting, incorporating organic matter and manure or composts. Starting with a good nutrient status in the soil is vital for rapid establishment. Plant the trees with a fork to avoid panning which will interfere with drainage and root growth. The trees should be staked and rabbit guards used. A mulch of straw, compost, black polythene or other suitable material directly around the young tree aids establishment and weed control. More information on methods of establishment for organic trees is required especially with regard to weed, pest and disease control.

3.4.3. Rootstock

Apple

The rootstock determines the overall height, vigour, rooting system, number of years to bear fruit, and the earliness of the fruit. The rootstock must be compatible with the variety grown on it, and different varieties will grow with different vigour. It is important that the rootstock is certified as healthy and free of viruses. Rootstocks are named by letters and numbers. The letter indicates where it was bred and the number merely refers to the serial number that it bore when it was under trial. The magnitude of the number does not necessarily relate to the size of the final tree. The ascending order of size of some common rootstocks grown under conventional conditions is as follows: M27 (Extremely dwarf 1-2m), M9 (very dwarfing), M26 (dwarfing), MM106, (approx. 3m) and MM111(up to 5-6m).

For an organic system the tree needs to be vigorous and tall enough to compete with weeds during establishment, yet provide a tree of suitable height to allow access without using ladders. This makes pruning, picking, spraying and inspection for pests and diseases on the tree much easier.

The extremely dwarfing rootstock M27 is probably not suitable for organic production as it is not vigorous enough and can only be used on very good soils. Small trees also tend to produce fruit which is close to the ground and therefore more prone to Phytophthora rot (*Phytophthora syringae*) which contaminates fruit by rain splash (Upstone, 1978). M9 is used by some organic growers and appears successful with many varieties including Discovery. Polythene is used as a mulch within the rows to keep the weeds down in this system (Lovelidge, 1990). MM106 and MM111 are more vigorous rootstocks. MM111 is suggested by another organic grower for most varieties (Hall, 1997). Due to its vigour this rootstock should have the ability to withstand the lower levels of nitrogen experienced in an organic system. However, its size would need to be kept in check by rigorous pruning. Rootstock is known to affect the storage of varieties, possibly by partition of nutrients to the fruit. For example, apples on the more vigorous rootstock MM111 are more prone to scald than M26 (Emongor *et al*., 1994).

More information on the performance of rootstocks in organic systems and nutrient regimes under UK growing conditions is required before recommendations can be made about appropriate rootstocks with any certainty.

Pear

Pears are normally grown on Quince rootstock. The most commonly available are Quince ‘A’ and Quince ‘C’. Quince ‘C’ produces slightly smaller trees which tend to fruit a little earlier and is less tolerant to poor soil than Quince ‘A’.

3.4.4. Choice of variety

Several varieties of compatible pollination type need to be grown in the same orchard. Resistance to scab and mildew is of paramount importance. Unfortunately, Britain’s favourite home produced apple ‘Cox’ is not suitable for organic production because it is so susceptible to many diseases especially scab, and does not remain crisp in store. Resistance to storage rots and susceptibility to physiological disorders should also be considered. There are large differences in the expected storage life of varieties. A range should be chosen to spread marketing and also harvesting, making efficient use of labour. Likewise the end market should be considered, the most suitable desert varieties may not always be suitable for processing.

There is very little information available on suitable varieties for organic systems and there appear to be very few varieties available with appropriate combinations of disease resistance and storage characteristics. For example Discovery apples are resistant to scab and mildew but do not store. Conference pears store well in refrigerated storage but are susceptible to scab. Fiesta (Red Pippin) apples are promising they store well but little is known about their resistance to storage rots (see table 24). Breeding programmes at HRI East Malling are screening for resistance to storage rots but it will be sometime before new cultivars will be contributing to the UK market (Berrie, 1992).

Table 24 Diseases resistance characteristics and storage life of some apple and pear varieties.

	Max. storage life in air	Scab	Canker	Mildew	Fireblight	Brown rot	Bitter pit
Apple							
Cox's orange Pippin	Mid Oct	S	S	S	S	S	S
Bramley's seedling	Nov	SS	-	R	-	-	S
Crispin	Jan	VS	S	R	S	-	S
Discovery	End Aug	R	-	VR	-	-	-
Egremont Russet	Dec	VR	R	R	-	-	S
Ellison's Orange	Dec	VR	S	VR	-	-	-
Fiesta (Red Pippin)	Jan	-	-	-	-	R	-
Gala	Jan	S	S	R	VS	-	-
Golden delicious	Jan	R	-	R	VR	-	S
Grenadier	Mid Oct	VR	VR	R	-	-	-
Idared	March	R	VS	S	S	-	-
Jonagold	Jan	-	-	-	-	-	-
Laxton's superb	Feb	S	R	R	-	-	-
Lord derby	Dec	R	R	R	-	S	-
Spartan	Jan	R	VS	VR	VR	-	-
Worcester Pearmain	Dec	S	S	VR	-	-	-
Pear							
Beurre Hardy	Dec	R	-	-	SS	-	-
Conference	April	SS	S	S	SR	-	-
Doyenne du Commice	March	SS	-	SR	VS	-	-

VS Very susceptible S Susceptible
SS Slightly susceptible T Tolerant
SR Slightly resistant R Resistant
VR Very resistant I Immune
- No information
(Crawford, 1997)

3.4.5. Understorey

Most organic systems either mulch directly around the tree and have a grass/clover (or other grass) strip between the rows, or grass is grown right up to the tree. Large areas of bare ground should be avoided as they favour the spread of storage diseases such as *Phyophthora syringae* which are dispersed by rain splashing up from the soil (Upstone, 1978). Weeds will also need to be continually controlled by cutting the sward or hand digging/removal.

The understorey can be put to good use cutting and mulching can be used to supply nutrients. Other areas can be used to either plant or encourage wild flowers particularly the *Umbelliferae* to attract beneficial insects such as parasitic wasps which will attack insect pests. Rough areas around the orchard in hedges and shelter belts also provide essential overwintering sites for beneficial insects (Crowder, 1994). Shelter belts and hedges also provide habitats for other wildlife and are an important component in organic systems.

More research is needed on the effects of the understorey; its contribution to nutrient levels or conversely its competition with the trees, its effects on orchard pest levels and methods of management. Some of this work is currently being investigated in New Zealand. The use of a permanent understorey probably encourages earthworm populations which are important for decomposition of fallen leaves. Diseased leaves are an important source of some fungal diseases such as *Venturia inaequalis*. More information on methods to encourage earthworms and rapid breakdown of leaves is required. Urea can be applied in conventional systems if leaf fall is late and earthworm activity has ceased. In India cattle urine is used instead of urea to help breakdown the leaves (Berrie, 1997, pers. comm.).

3.4.6. Nutrient requirements

Supplying enough nutrients in apple orchards, especially nitrogen has been highlighted as a problem (Hall, 1997). Organic sources of nutrients are composted manures, composts, green manures and foliar feeds such as sea weed extract. More information on nutrient requirements and how they can be supplied using organic fertilizers is required.

The nutritional components of the fruit, especially levels of calcium affects physiological disorders such as scald but it also affects the resistance of fruit cell walls to some rot fungi (Sharples & Johnson, 1977). Correct mineral status of the fruit also renders it more resistant to lenticel-invading fungi such as *Nectria galligena* or *Gloeosporium* spp. (Sharples, 1980)

3.4.7. Pruning

Pruning is a vital part of organic fruit growing. Light should be able to penetrate through the framework to allow ripening. It is also important to establish the framework at the appropriate height for cultural operations.

All dead and damaged wood should be pruned out, along with any diseased wood. Several of the storage diseases persist over the winter in diseased wood, cankers and mummified fruit. These become the source of infection the following year. Dead wood should be chipped to allow rapid rotting if it is left on the orchard floor. Alternatively wood can be gathered and burnt but this is time consuming and removes valuable nutrients from the orchard.

3.4.8. Summer pruning

This needs to be carefully undertaken during dry weather because of the risk of spreading *Gleosporium* spp canker etc. The secateurs should be sharp to lessen the risk of infection. Summer pruning will improve the finish of apples. Not too much vegetative growth should be removed as this can result in smaller fruit size. Diseased wood should also be cut out at this time (Cherry, 1991).

3.4.9. Spraying to prevent storage diseases

Sprays to control scab (*Venturia inaequlais*) and powdery mildew (*Podosphaera leucotricha*) are routinely used in organic orchards which have been shown to have a problem. One regime used by Congelow (Congelow, 1989, pers. comm.) is as follows:

Sulphur (4Kg per acre) and seaweed extract (a foliar feed at 1.1 litres per acre) in 227 litres of water can be applied every 10-14 days from bud burst until the green cluster stage and then again from petal fall to early August.

Sulphur is also known to reduce *Gloeosporium* spp. and *M. fructigena*. Copper fungicides are also permiited by the UKROFS standards. Bordeaux mixture (copper sulphate and lime) is more effective than sulphur and will also reduce *N. gallingena* slightly (Walker, 1957). The drawback of using bordeaux mixture is that it can also cause russetting and damage to fruit, not only is this unacceptable to the market but it can provide entry wounds for storage rots. Some varieties are far more sensitive than others. Sulphur is less effective against fungal diseases but causes less direct damage to the fruit. Again some varieties are more sensitive than others.

Calcium chloride foliar sprays are allowed according to UKROFS to control scald and bitter pit of apple, provided it has been shown that the trees are deficient and approval is sought from the inspecting body.

3.4.10. Irrigation

Withholding irrigation either for the whole of the growing season or late in the growing season can increase flesh firmness at harvest and storage in conventionally grown ‘Braeburn’ apples. Weight loss during storage can also be reduced. However, withholding irrigation will also cause the fruit to mature more quickly and to ripen earlier so that harvest times may need to be adjusted (Kilili, *et al*., 1996). Total yield and size of fruit may be reduced but this needs to be off-set against the increased quality achieved after storage. In larger fruited varieties the reduction in fruit size is probably less of a concern. Withholding irrigation did not affect the fruit calcium concentration, therefore scald incidence is unlikely to be affected.

3.4.11. Correct maturity

Fruit must be picked at the correct stage of maturity. Fruit which is picked immature is more prone to shrivelling in storage. Late picked fruit will be over mature, will not store as long and will be more prone to rot fungi. The longer the fruit is left on the tree, the greater the risk of exposure and infection by rot fungi, especially those spread by rain (Berrie, 1992). In pears an iodine test is used to indicate the ratio of starch to sugar. This provides a guideline as to whether the fruit is at the correct stage of maturity.

3.4.12. Conditions at harvesting

Correct stage of maturity governs the harvesting date, but harvesting when the fruit is wet should be avoided. Any wet fruit should be laid out to dry before being stored.

3.4.13. Postharvest handling

The crop should be handled very carefully at harvesting. Many rot fungi particularly brown rot (*Monilinia fructigena*), mucor rot (*Mucor pyriformis*) and blue mould (*Penicillium expansum*) enter fruits through wounds caused either by rough handling, or through natural cracking and russetting. Care should be taken to avoid fruit being contaminated with soil. This can introduce *Phytophthora syringae* and *Mucor* (Berrie, 1992). Only healthy fruit should be selected for storage. Bulk bins contaminated with the previous years rotten fruit are also sources of rot fungi especially *Penicillium* and *Botrytis* (Berrie, 1992).

The temperature of the fruit at the time of injury can affect the degree and colour of bruising. Some varieties are affected more than others. For example, 'Granny Smith' and 'Jonathan' apples show darker bruising when the fruit were stored at 0°C than 10 or 20°C for 4 days. Current packhouse practice where fruit is packed cold are probably increasing levels of bruising during packing. Packing while the crop is still at field heat or raising the temperature of cold-stored apples before packing will probably result in less injury. Other varieties such as 'Golden Delicious' are no more sensitive to injury at 0°C than 10 or 20°C (Thomson, *et al*., 1996). However, there may be practical problems associated with trying to cool the produce once it has been packed and delaying cooling may reduce storage life.

Refrigerated cold stores can be inspected regularly and any rotting fruit removed. Many storage rots can produce spores which can easily be blown around the store, so any movement of infected material should be done with care. Dormant spores will infect the crop if conditions become favourable e.g. any condensation on the crop or if store temperatures rise.

3.4.14. Predicting storage life

A research programme is currently being carried out at HRI, East Malling to develop a system to predict the storage potential of a crop. The system is most developed for Cox but work is also being carried out on other varieties. Development of this type of predictive system could be very useful if it could be tailored for organic production. However, so little information is available about the growing of organic top fruit and even which diseases are likely to develop in store, that a lot of ground work needs to be covered first.

Factors which the system uses to predict storage potential are:

- The fruits mineral composition (determined by analysis).
- The orchards previous rot history (but it can be difficult to get growers to make records especially from separate orchards).
- Orchard factors (such as hail damage, cracking and russetting, crop load).
- Conditions at petal fall (when botrytis can gain access).
- Conditions during July, August, and September.
- Soil management (amount of ground cover by grass, mulches and weeds).
- Amount of fungal rot inoculumn (determined by numbers of cankers, mummified and infected fruit, eye rots and infected fallen fruit).
- Proportion of crop 0.5m above ground level.

(Berrie, 1992).

The development of rapid diagnostic tests to determine levels of infection on fruit and their potential storage capability would also be useful.

3.5. STORAGE METHODS

3.5.1. Introduction

Clamps, and ambient air cooled stores are not suitable for storage of fruit. Storage temperatures and humidity can not be sufficiently regulated to avoid shrivelling and loss of firmness. Ambient air cooled storage may be suitable for transient storage for a box scheme but even then a refrigerated lorryback or shipping container would be preferable (see sections 2.8 and 2.3.13.3.).

Direct refrigerated cooling with a humidyfing system such as a pad humidifier is recommended by FarmElectric (a) (see section 2.3.13.2.). Positive ventilation systems and moist air cooling will be needed in box stores (see section 2.3.15.). Hydrocooling (see section 2.3.13.1.) is only regarded as satisfactory, it is expensive and can spread fungal storage diseases such as *Penicillium expansum*.

3.5.2. Refrigerated cool storage of apples in air

HRI, East Malling, last reported its recommendations for storage of apples and pears in 1985 (Sharples & Stow, 1986). There have been some revisions since then to account for present market requirements for firmer fruit (Johnson, 1997, pers.comm.).

The recommendations to date are given in Table 25. The maximum storage life should be treated as a guide only as it assumes that the apples have been conventionally grown and treated to prevent rots, bitter pit and scald. Unfortunately guidelines specifically for organic fruit were not found in the literature review. As for vegetables the optimum storage regimes for conventional fruit take into account the avoidance of storage rots, chilling and physiological disorders. Therefore, they are useful guidelines for the organic crop.

The storage regimes given in Table 25 also assume that store operating temperatures are achieved within 5 days of loading. Holding temperatures should be close to the average of the temperatures given. Where the difference between the maximum and minimum temperatures exceeds 0.5°C, the lower temperature should be observed and a higher average fruit temperature accepted. It is very unwise to store the below the minimum temperature where it is close to the freezing point of the fruit.

Table 25 Recommendations for air storage of apples.

Variety	Fruit temp. °C	Up dated terminate month(1997 data)	Terminate month (1978 & 1986)	Notes
Bramley's Seedling	**3.0-3.5**	**Nov**	**1,2,3**	
Cox's Orange Pippin	**3.0-3.5**	**Mid Oct**	**4,5**	
Charles Ross	3.0-3.5	-	Nov	
Chivers Delight	4.5-5.0	-	Dec	1
Crispin	**1.5-2.0**	-	**Jan**	1
Discovery	**3.0-3.5**	-	**End Aug**	**6,7**
Edward VII	3.0-4.0	-	Jan	1
Egremont Russet	**3.0-3.5**	-	**Dec**	8
Ellison's Orange	4.0-4.5	-	Dec	11
Elstar	0-1.5	-	Jan	
Fiesta	**1.0-1.5**	**Jan**		
Gala	**0-1.5**	**Jan**		
Gloster 69	0-0.5	-	Jan	
Golden Delicious	1.5-2.0	-	Jan	1,12
Grenadier	0.0-1.0	-	Mid Nov	
Holstein Cox	3.0-3.5	-	Mid Dec	
Howgate Wonder	3.0-4.0	-	Jan	1
Idared	**3.5-4.5**	-	**March**	9
Ingrid Marie	1.5-3.5	-	-	
James Grieve	3.0-3.5	-	Oct	
Jonagold	**0-0.5**	**Jan**		
Jonathan	3.0-3.5	-	Jan	
Jupiter	3.0-3.5	-	Nov	1
Katy (Katja)	3.0-3.5	-	End Sept	7
Kent	3.5-4.0	-	March	
Kidd's Orange	3.0-3.5	-	-	
Laxton's Fortune	3.0-3.5	-	Nov	
Laxton's Superb	**1.5-3.5**	-	**Feb**	
Lord Derby	3.0-4.0	-	Dec	
Lord Lambourne	1.5-2.0	-	Jan	
McIntosh	3.5-4.0	-	Mid Dec	13
Melrose	0.0-0.5	-	Jan	
Red Delicious	0.0-1.0	-	Jan	
Spartan	**0.0-0.5**	-	**Jan**	**10**
Sunset	1.5-2.0	-	Jan	
Suntan	3.5-4.0	-	Jan	14
Tydeman's Late Orange	3.0-3.5	-	Feb	
Winston	0.0-3.5	-	April	
Worcester Pearmain	**0-1.0**	-	**Dec**	8

The information for varieties in bold is either well established or has recently been updated.
Varieties in noramal script are either less common or the storage recommendations are more experimental.
Relative humidity should be at least 90% preferably as near to 96% as possible.

Key

Symbol	Explanation
-	No data available
1	Risk of superficial scald, use calcium chloride foliar spray.
2	Slight risk of low temperature injury especially if late picked or fruit phosphorous is<9mg/100g.
3	Ethylene scrubber would be beneficial to reduce bitter pit risk.
4	Storage of Cox only worthwhile when fruit calcium > 5mg/100g, potassium 150mg/100g maximum. Avoid late picking.
5	After cool summer, maintain minimum fruit temperature of 4°C to reduce risk of low temperature

Symbol	Explanation
	injury.
6	Cool quickly, preferably using forced air cooler
7	Maximum post-storage life of 4-5 days
8	Risk of shrivel; reduce by loosely covering the top layer of fruit in each bin with polythene liners.
9	Risk of coreflush during distribution through market
10	Risk of breakdown if fruit Calcium <4mg/100g; apply calcium sprays and/or treat postharvest with calcium chloride
11	Susceptible to soft scald a form of low temperature injury
12	Risk of coreflush and breakdown in some years at temperatures below 1.5°C in air
13	Pick mid September
14	Risk of low temperature breakdown after January

Compiled from Sharples & Stow (1978 & 1986) and Johnson (1997)

3.5.3. Apple varieties which can be stored together in air

Sometimes it is not possible to fill a whole store with one variety. Mixing varieties is not generally recommended as different varieties require different optimum conditions and release different levels of ethylene. Some varieties are more responsive to ethylene than others; one variety releasing ethylene will cause another to senesce more rapidly.

Table 26 from Sharples & Stow, (1978 & 1986) shows which varieties can be stored together with reasonable success. This practice is only advisable if the only other alternative would be to use part empty chambers. It is assumed the store will have to be opened before the recommended terminate month of the variety which will store for the least amount of time.

Table 26 Varieties of apple which may be stored in the same chamber in ordinary air for short periods.

Fruit temp.	Varieties
1.0 - 2.0°C	a) Worcester Pearmain, Lord Lambourne, Winston and Spartan
	b) Crispin* and Golden Delicious*
3.5 - 4.5°C	Cox's OP, Spartan, Laxtons Superb, Idared, Tydeman's LO, Egremont Russet and Laxton's Fortune
	b) Bramley*, Edward VII*, and Howgate Wonder*

* These varieties are susceptible to scald and if grown conventionally it is normally recommended that they are treated with an anti-scald chemical. For organic storage, foliar sprays with calcium chloride are permitted provided permission is granted from the symbol holding authority.

3.5.4. Recommended cold storage conditions for pears (in air)

The flesh of Conference pears is relatively hard, consequently it is a relatively easy to store for a long time in air at -1° C to -0.5° C. Controlled atmosphere storage for this variety is not really necessary (see Table 27).

It is important to pick pears when they are at the correct stage of ripening. A starch-iodine test should be used to judge maturity. If the soluble solids content of the fruit is below 11% e.g. after cool sunless summers, the minimum storage temperature should be raised by 0.5° C. It is important that field heat is removed quickly. The crop should be cooled to 4° C within 2-3 days of loading and the recommended storage temperature should be achieved within a further 7-10 days. If the store cannot be maintained below 0° C storage should be terminated earlier. The relative humidity of the store should be above 90% and as near to 96% as possible. After storage pears should be conditioned at a higher temperature and before distribution and sale.

As the storage temperature of pears is very close to their freezing point it is important to set a second, over-riding, thermostat to cut the refrigeration plant out when the temperature of the air leaving the cooler falls to -2° C.

Table 27 Recommended storage conditions in ordinary air for the main varieties of pear.

Variety	Fruit temperature	Terminate Month
Beurré Hardy	-1.0°C to -0.5°C	December
Conference		April
Doyenné du Comice		March
Williams' Bon Chrétien		November
Concorde		January

(Sharples & Stow, 1986)

3.5.5. Pear varieties which can be stored together in air

It is not normally recommended that different varieties should be stored together.As with apples different varieties release different levels of ethylene and show differing sensitivities to this gas. One variety may adversley affect the storage of another. However, Conference and Doyenné du Comice pears can be stored together in air at -1.0° C to-0.5° C.

3.5.6. Costs of cold storage

The costs of storage will vary with the size of store, degree of insulation and length of storage. Based on information gathered for vegetable box stores (see section 2.5. Case study, 8) and costs of conventional apple stores (Hardy & Luton 1997). This is likely to range from £30-40/ tonne.

3.5.7. Controlled atmosphere storage

(also see section 4.1.)

At present controlled atmosphere storage is not required. The small quantity of UK organic fruit crop produced can be stored in humidified refrigerated storage and marketed before it looses firmness. There are a number of drawbacks with using controlled atmosphere storage, it is relatively expensive and not very conducive to storing small quantities of fruit as the store chamber must be full to work efficiently. However, conventional growers converting to organic production are likely to have access to controlled atmosphere storage and there may even be the option that they could hire out excess storage space to existing organic growers.

For optimum performance of controlled atmosphere storage, the conditions have to be tailored to the variety, the levels of nutrients in the fruit (such as calcium), and the growing conditions of the crop. Usually, in an organic apple crop, it is difficult to deliver enough nutrients into the system, therefore the nutrient status of an organic crop is likely to be different from a conventional one. Research would be needed to determine if organic apples and pears require different storage conditions from conventional. This work would need to be specific to the UK as even optimum storage conditions of conventional fruit tend to vary from country to country (Thompson, 1996).

Conventional apples are dipped to prevent physiological disorders such as superficial scald which can develop where ultra low levels of oxygen are used for prolonged periods. Without the use of dips expected storage life may be reduced. Research at Horticulture Research International, East Malling is being carried out on CA conditions which do away with the need for dips such as diphenylamine and ethoxyquin to control superficial scald. Johnson, *et al.,* (1996) showed that delaying the increase in carbon dioxide in a controlled atmosphere store by 5 days gave reasonable protection against carbon dioxide injury and is likely to be a good compromise for scald control.

Reduced levels of oxygen can actually increase frequency of some storage rots e.g. *Pezicula malicorticis* (Bompeix, 1978) and growth is unrestricted in most postharvest pathogens down to about 3-4% oxygen. At levels below 1-2% growth rate is dramatically reduced. Levels below 1% oxygen get dangerously near the point of low oxygen injury to the fruit (Sommer, 1985). By carefully manipulating levels of oxygen, carbon dioxide and temperature, controlled atmosphere storage can successfully delay the onset of storage rots by delaying scenescence and by directly reducing the growth of rot producing fungi (see section 4.1.6.).

Based on a 50t chamber and a capital cost of £25,000, the annual costs of controlled atmosphere storage are given in Table 28.

Table 28 Costs of controlled atmosphere storage

	£	**£/tonne**	**p/lb**
Depreciation (over 10 years)	2500		
Interest on capital 6%	1500		
Running costs (£5.5/t)	275		
Repairs and maintenance	375		
Total costs	**4650**	**93**	**4.2**

(Adcock, 1997)

3.5.8. Ethylene scrubbing

Ethylene is an important gas produced by the fruit itself which controls ripening. The higher the levels of ethylene, the faster fruit become soft and over mature. Ethylene scrubbers can be used to remove ethylene from either controlled atmosphere stores or ordinary air stores (Dover, 1989). The removal of ethylene by external scrubbers tends to increase temperatures in the store, therefore cooling systems have to operate for longer periods of time and this can cause increased water loss (shrivelling) of the crop. It has been found in small scale experiments on ‘Cox’s Orange Pippin’ that ethylene does not have to be removed from the store for the whole of the storage period. After 12 weeks of ethylene scrubbed storage no benefit was seen over ethylene scrubbing for the whole storage period of 29 weeks (Dover & Stow, 1993)(also see section 4.2).

3.6 STORAGE DISEASES OF APPLES AND PEARS

The most common post- harvest rots in conventional apples and pears are given in Table 29.

Table 291 Common storage rots in conventional apples and pears.

Infection in orchard	**Infection after harvest**
Brown rot (*Monilinia fructigena*)	Botrytis rot (*Botrytis cinerea*)
Gloeosporium rot (*Gloeosporium* spp)	Blue mould (*Penicillium expansum*)
Nectria rot (*Nectria galligena*)	Mucor rot (*Mucor pyriformis*)
Phytophthora rot (*Phytophthora syringae*)	Fusarium rot (*Fusarium* spp)
Botrytis rot (*Botrytis cinerea*)	
Black rot (*Botryosphaeria obtusa*)	
Diaporthe rot (*Diaporthe perniciosa*)	

(Berrie, 1992)

Many of the above diseases may also be a problem in organic fruit but not necessarily as cultural conditions are different. In conventional crops benzimidazole fungicides (e.g. benomyl, carbendazin, thiophanate-methyl) successfully control some of the rot fungi (e.g. *Gloeosporium* spp.) but often the absence of one disease on the fruit surface just makes way for another which is not affected by that particular fungicide. The profile of storage diseases could therefore be different in organic fruit, especially amongst the less common fungi.

Information on storage rots in UK organic top fruit has not been drawn together and published. The profile of diseases experienced on organic fruit in other countries do not provide particularly useful information as growing conditions vary widely around the globe. Therefore, it is difficult to predict which storage diseases may become a problem in organic fruit. Pre-harvest and postharvest fungicide treatments, controlled atmosphere storage and nutritional status of the fruit are all known to influence the incidence and severity of storage diseases (Berrie, 1992).

A survey of storage losses in ‘Cox’ apples carried out during 1961-1965, before the widespread use of postharvest fungicides, revealed that Gloeosporium rot (*Gloeosporium* spp.) was the main cause of storage losses with levels of 30% in the worst affected stores (Preece, 1967). Brown rot (*Monilinia fructigena*) was also important. These two diseases may be of importance in organic systems but knowledge of the factors which affect storage diseases and the optimum regimes for air storage have developed since then.

Other diseases, most noticeably Phytophthora rot (*Phytophthora syringae*) which is now far more common in conventionally stored ‘Cox’, were insignificant or not present at all in the survey in the 1960’s (Berrie, 1992). This disease is probably less likely to occur in organic crops where an understorey is used or the ground is mulched directly around the trees to control weeds. Relatively little bare soil will be exposed, making the dispersal of the disease in rainsplash from the soil to the fruit less likely. At present *Diaporthe perniciosa* is unlikely to be a problem, it is a saphrophyte and does not usually appear in the first two or three months of storage. It is slow to manifest itself in storage, but may be a problem if controlled atmosphere storage is ever used.

In 1946, before modern fungicides were used and growers were habitually using many of the sprays used by organic growers today. *Molinia fructigena, M. laxa, Gloeosporium fructigenum, G. album, G.perennans, Fusarium spp., Venturia inaequalis, Penicillium expansum, Botyrtis cinerea* and *Diaporthe pernicosa* were all mentioned as causing storage problems at this time. Other minor fungal diseases recorded were *Pleospora pomorum, Polyopeus purpureus, Trichothecium roseum, Sphaeropsis malorum* and *Rhizopus nigricans* (Wormald, 1946). These diseases are not mentioned in modern surveys or disease books. There may just be some confusion over nomenclature but they could be potential problems currently controlled by modern dips and sprays.

Several of the common postharvest diseases infect before harvest. Important sources of spores and direct infection by mycelium are from mummified fruit and cankers (*M. fructigena, Nectria gallingena* and *Gloeosporium* spp), infected or dead twigs and branches (*Gloeosporium* spp, *B. cinerea, M. fructigena, M. laxa, N. gallingena*). If practical, all mummified fruit should be collected and burned. Cankers, dead and diseased wood should be pruned out.

Woolly aphids can spread *N. gallingea*. These can be controlled with spot spraying of soft soap and use of resistant rootstocks. Other insect pests such as wasps, larvae of the codling moth (*Cyphia pomonella*) and apple sawfly (*Hoplocampa testudinea*) should also be controlled as these cause damage and encourage rots such as *M. fructigena*.

Strictly speaking scab (*Venturia ineaqulis*) is not regarded as a storage disease in itself. Although it can develop in store from lesions unnoticed at harvest. In relation to storage diseases it should be considered because it damages the cuticle of fruit and can cause cracking allowing easy entry of other rots such as *M. fructigena*. It also damages young branches allowing *N. gallingena* to take hold. The sprays permitted by the organic standards to control scab also help control some of the storage diseases by reducing inoculum before harvest. (see section 3.4.9. for sprays).

3.7. PHYSIOLOGICAL STORAGE DISORDERS

3.7.1. Superficial scald

This physiological disorder which affects both apple and pear, is characterized by browning of the fruit skin, with some russetting or pitting if the disease is severe. If the damage is slight the affected areas of the skin only have a slight brownish tinge in contrast to the yellow and green ground colour of the surrounding apple skin. The skin may also be slightly rough due to moisture loss. In severe cases the browning may reach a depth of 0.5 cm into the flesh. The scald lesions readily become infected with rot-producing fungi. Improperly matured fruit usually suffers more and some varieties are more prone to scald than others e.g. 'Delicious', Granny Smith', 'Bramley's Seedling' and 'Cortland' are all susceptible but Empire is more tolerant (Meigh, 1970.; Meir & Bramlage, 1988).

The biochemical cause of scald is thought to be due to the oxidation of α-farnescene a naturally occurring essential oil in the fruit skin. Low oxygen conditions as found in controlled atmosphere stores decrease the severity of the disorder. Scald is also prevented if naturally occurring anti-oxidants remain at sufficient levels during the growing season, harvest and in store. Scald is also less likely where high levels of ascorbic acid and flavonals occur in the skin (Ingle & D'Souza, 1989).

Hot water dips can be used to reduce scald in some varieties. Dips at 54°C were found to inhibit scald in 'Stayman' and 'Delicious' apples but were less effective in 'Rome Beauty' (Ingle & D'Souza, 1989). Pre-storage heat treatment of 4 days at 38°C gave control on 'Granny Smith' for 4 months stored in air, and for 9 months in controlled atmosphere storage (Lurie *et al*., 1990). Low oxygen (1% or lower) in combination with a 'safe' high carbon dioxide concentration (such as 5% for Bramley) and ethylene scrubbed storage atmospheres can reduce the incidence of scald (Little & Peggie, 1987) (see also section 4.3).

A number of pre-harvest factors are known to affect the incidence of scald in storage these include weather conditions, soil type, soil moisture, soil management, rootsocks, age of tree, spacing, pruning and fruit size but often trials gave conflicting results (Emonger *et al*., 1994). Models using factors such as night temperatures have been developed with varing degrees of success to predict susceptibility to scald (Emongor, *et al*., 1994).

Maturity and harvest date have long been known to affect the development of scald in storage. Usually fruit harvested early is more prone but for some varieties this is not the case. For example, over mature fruit of some varieties such as ' Delicious' scald more severely than early picked fruit.(Emongor, *et al*., 1994).

Nutrition can affect scald. Low levels of calcium in the fruit increase scald development and levels of phosphorous may have an influence (Emongor, *et al*., 1994). Foliar treatments with solutions of calcium chloride are permitted (in UKROFS Standards) if the need can be demonstrated. However, postharvest dips of the fruit are considered more effective.

High potassium levels in the fruit and/or leaves, and high nitrogen applications or late applications are also thought to have an effect, but whether the effect is positive or negative can be dependent on the general nitrogen status of the orchard and the availability of other soil nutrients. The effects are probably associated with the increased vigour of trees fed with nitrogen, causing lower calcium in the fruit due to dilution (Emongor, *et al*., 1994). Organic fruit is probably less likely to suffer from excess nitrogen and therefore scald. Very little is known about the effects of other nutrients but there is some evidence to suggest that copper and cobalt increase scald while barium and strontium decrease the disorder (Emongor, *et al*., 1994)

More information on the effects of nutritional status on physiological disorders would be useful.

3.7.2. Bitter pit of apple

This disorder is considered to be due to a mineral imbalance in the fruit; low levels of calcium and high levels of potassium. Very hot dry summers (Western Australia) also increase the incidence of the disorder. Calcium salt foliar sprays are reported to control the problem but under commercial conditions postharvest dips are more effective. However, some varieties are susceptible to damage by the calcium salt itself. (Shorter, *et al*., 1992) and postharvest dips are not permitted by UKROFS.

3.7.3 Retaining firmness using pre-storage heat treatments of apple.

Hot air heat treatment of apples immediately after harvest at 38°C for 4 days prior to storage maintains firmness and texture for a longer period of time than those immediately reduced to their final storage temperature of 0°C to -1°C and relative humidities of 90- 95%. This has been demonstrated in several varieties including ‘Golden Delicious’ and ‘Granny Smith’ (Lurie & Nussinovitch, 1996), and ‘Anna’ (Shalom *et al*., 1996). Firmness was retained to a greater extent in shelf life tests after the heat treatment and storage. Heat treatments are are promising technology for organic top fruit but they involve considerable extra cost and further development work is required before they are commercially viable (see also section 4.3.)

3.8. BIOLOGICAL CONTROL OF FRUIT STORAGE DISEASES

There has been some research effort mainly in the USA and Israel on postharvest biological control. A range of biological control agents to control blue mould, grey mould, mucor rot, *Monilinia rot and Rhizopus* rot have been researched (Droby & Chalutz, 1994). As yet only two commercial preparations are available. For further information on biological control see section 4.5.

3.9. OTHER PREPARATIONS

There are some preparations available in the EU which may be suitable for use in the UK. For example, 'Myco-Sin which contains processed aluminiumsulphate (sulphuric argilaceous earth), yeast components, extracts from horsetail and organic wetting and adhesion compounds. It appears to enhance the plants natural immunity to a range of fungal diseases and could be used on a range of crops including top fruit. It is used in Switzerland to control apple-scab (*Venturia inaequalis*). At present it is not registered for use with COPR or the PSD. In principle UKROFS would consider its use as it is used in organic systems abroad. It would be useful to carry out trials on its efficacy in the UK.

4. NEW RESEARCH AND TECHNOLOGY DEVELOPMENT

4.1. CONTROLLED ATMOSPHERE STORAGE

4.1.1. Introduction

Controlled atmosphere storage works on the principle of removing oxygen from the store atmosphere and increasing the levels of carbon dioxide so that crop respiration is slowed down thereby prolonging the storage life of the crop. This effect is usually enhanced by cool conditions so the stores are also refrigerated. Levels of ethylene, which control ripening, can also be removed from the store atmosphere to lengthen storage life. It can take some considerable time for the correct levels of gases to be reached so in practice nitrogen is commonly injected into the stores to evacuate oxygen quickly. This method is especially useful where the store does not have a good seal, it can be kept at positive pressure so that untreated air cannot get in.

The levels of gases in the store have to be carefully regulated or physiological damage, tainting of flavour and loss of texture are but a few of the symptoms that can occur if things go wrong. Crop species, variety, mineral status of the crop and conditions during crop growth are all known to affect the required optimum levels of oxygen and carbon dioxide. For these reasons it is not possible to store different crop species together, nor is it advisable to store different varieties together.

Controlled atmosphere storage is expensive. The store needs to be airtight and equipment is required to monitor the levels of gases as well as add or ‘scrub’ these gases. For this reason it is only worthwhile using controlled atmosphere storage if the crop can be sold for a premium after storage, or where refrigeration alone is not enough to guarantee long term quality. As a consequence only conventional apples, pears and to a lesser extent cabbage are stored using controlled atmosphere. Research effort has been placed into controlled atmosphere storage for other crops but as yet there is mixed success.

At present, organic vegetables and fruit are not stored in controlled atmosphere and its use has not been considered by UKROFS, therefore, strictly speaking it is not permitted by UK organic standards. However, controlled levels of oxygen, carbon dioxide and nitrogen are permitted according to EU and IFOAM regulations and it is probable that UKROFS would consider that controlled atmosphere storage is within keeping with the spirit of the standards (Crofts, 1997 pers. comm.). Removal of ethylene is not mentioned in EU or IFOAM standards, so no precedent has been set for its use. It is important that the status of all forms of controlled atmosphere for all crops is clarified in the UKROFS standards. This is especially the case for top fruit, where controlled atmosphere storage is the only option available to keep produce beyond 2-3 months to the high standards of quality required by the present market.

4.1.2. Controlled atmosphere storage of cabbage

There is some controlled atmosphere storage of conventional cabbage in the UK and Europe. Suggested levels of carbon dioxide and oxygen vary in the literature, probably because different cabbage types and varieties require different conditions (Thompson, 1996). Controlled atmosphere storage of organic cabbage would probably require some development work.

4.1.3. Potential for controlled atmosphere storage of onions.

Controlled atmosphere storage of conventional onions is used in the USA to store ‘Grano’ onions which normally only store for 6 weeks in ambient conditions. In the UK controlled atmosphere storage is used to store Rijnsburger onions which already store well. By using 3% O_2 and 5% CO_2 and dehumidification these onions can store from harvest in September through to the following July. There are a number of drawbacks high cost (£300/ tonne, excluding boxes, plus £1.50/tonne/month for electricity) and the onions tend to sprout rapidly once they are exposed to higher temperatures and ambient air humidity. They need to be warmed to 20ºC for 3-5 days before they are cleaned and graded after storage and then should be marketed within 2 weeks of being removed from the store (Brice *et al.*, 1997).

It is unlikely that controlled atmosphere storage will be widely used in the UK for conventional onions. For organic onions it is may be worthwhile for long term storage beyond March where refrigerated storage without the use of sprout suppressants cannot guarantee that the crop will not sprout. However, store capacities need to be in the region of 300-600 tonnes for the system to be economical (Brice *et al.*, 1997). Collective storage may be an option, but this has its difficulties as different varieties require different conditions, so that only one variety can be stored in a chamber.

4.1.4. Potential for controlled atmosphere storage of potatoes

Controlled atmosphere storage of conventional potatoes is not practiced at present. The technology still needs a great deal of development. Sprouting can be controlled during 24 weeks of storage at 5ºC by high levels of carbon dioxide but to the detriment of fry colour. Low oxygen levels can also suppress sprouting but the dormancy status of the crop greatly affects the outcome. There is some evidence that low oxygen reduces the incidence of silver scurf and skin spot but increases soft rotting (Briddon & Cunnington, 1996).

It is unlikely that controlled atmosphere storage can be used for organic potatoes in the near future although there may be some scope for storage of ware potatoes. It is unlikely to be of use for the storage of processing potatoes due to the development of unacceptable fry colour.

4.1.5. Controlled atmosphere for storage of top fruit

Controlled atmosphere storage of conventional fruit is common practice since ordinary refrigerated storage does not maintain fruit quality for more than 2-3 months for most varieties. A great deal of research has been carried out to find optimum levels of oxygen, carbon dioxide and ethylene, which have to be tailored to the variety, the nutritional status of the fruit and even the growing conditions of the crop. HRI East Malling and various ‘Variety Clubs’ publish and update optimum gaseous levels and expected duration of storage for particular varieties.

Controlled atmosphere storage will be essential for organic apples and some varieties of pear for post-Christmas storage. If UKROFS clears the use of controlled atmosphere storage (i.e. regulation of oxygen, carbon dioxide and nitrogen) further research is likely to be required to tailor the exact levels of gases to the nutritional status and the growing conditions of organic crops and may well prove to be different from those required for conventional crops. There are also concerns amongst conventional fruit producers and researchers that the success of controlled atmosphere storage relies on the use of fungicidal dips to control storage diseases and dips to prevent physiological disorders.

Organic apples are currently stored using controlled atmosphere (O_2, CO_2, and N_2) storage in the US and Germany (Segger, 1997, pers. comm.) indicating that the technology can work but it is likely that only varieties which are more resilient to physiological disorders will be suitable. No published information on the gaseous levels required specifically for organic crops could be found in the present study.

4.1.6. Controlled atmosphere and postharvest diseases

Very low oxygen levels and very high carbon dioxide levels are known to inhibit various stages of growth and sporulation in a wide range of fungi. Controlled atmosphere storage has the potential to control many pathogens on a wide range of crops and is, therefore, an important method to consider for organic crops. The effect on fruit pathogens has been researched the most, and borne out in commercial storage.

Reducing concentrations of oxygen suppresses senescence in fruit (Sams & Conway, 1985) thereby maintaining the crops own resilience to weak storage pathogens. Low oxygen, especially at concentrations of 1% or less, can directly reduce growth, sporulation and germination of most postharvest fungi on Cox apples (Berrie, 1992). A similar reduction in rotting has been found by Edney (1964) and Bompeix (1978). To maximise the effects, the store must be loaded quickly and the store conditions rapidly established.

4.2. ETHYLENE SCRUBBERS

A possible alternative to the use of ultra low oxygen levels in controlled atmosphere storage is the use of ethylene scrubbers. Ethylene can be removed from stores using an aluminia carrier (Al_2O_3) impregnated with potassium permanganate. The granules can be placed inside the store or even inside the crop packaging. This form of ethylene scrubber has been rejected for use by UKROFS.

Ethylene scrubbers where the chemical components work remotely from the store are more likely to be acceptable. Here a catalytic converter removes ethylene from the store atmosphere to produce carbon dioxide and water. This requires a lot of energy but there are now energy efficient versions available. Ultra low levels of oxygen are not required, so an ethylene scrubber can be used where natural respiration reduces oxygen levels to 12% and carbon dioxide is increased to 9%. They are also useful where the store operator is not experienced with low oxygen controlled atmosphere storage, as the level of management required for ethylene scrubbers is not as great. Very low levels of oxygen can cause scald, flesh and core browning, these are not likely to be problems if an ethylene scrubber is used in combination with a higher level of oxygen. 'SWINGCAT' units are available (B.R.M. Agencies, 1997) for relatively small stores of 50 tonnes (£7,500) or one larger unit can be used to run several smaller stores with a total capacity of 200 tonnes (£10,500) or 400 tonnes (£12,500).

Although more costly than ultra low oxygen, ethylene scrubbers may be worthwhile for organic fruit as postharvest chemical treatments to prevent physiological disorders such as scald are not permitted. They are also suitable where several varieties or even species are stored together in ordinary refrigerated storage. The 'SWINGCAT' was originally developed to eliminate indoor gaseous pollutants, it therefore removes carbon monoxide, hydrocarbons, ozone and even microbial spores. Its potential use to control postharvest fungal and bacterial rots is yet to be proven.

4.3. HEAT TREATMENTS

Introduction

The use of postharvest heat treatments for fruit and vegetables is not specifically mentioned in UKROFS standards, but it is likely to be considered acceptable. The use of indirect heated air is of course permitted and considered essential for grain drying to prevent fungal diseases and pests. Heat treatment of vegetables and fruit is reviewed here briefly, with future research development it may have potential for use on organic crops e.g. fruit.

Heat treatments have been used commercially to control fungal diseases and insect infestations of fruit for many years and was first used in the late 1920's (Couey, 1989). Its use has mainly been confined to insect disinfestation of tropical or sub-tropical fruit, e.g. papaya, peaches, nectarines, cantaloupes and citrus fruits but has largely been replaced by chemical treatments (Harvey, 1978).

More recently there has been a resurge in research interest in the use of heat treatments to control postharvest pathogens, insect pests, physiological disorders e.g. scald and loss of firmness, and chilling injury. This is in response to increased fungicide resistance, the withdrawal of fungicides and fumigants such as ethylene dibromide, and consumer concern over the use of postharvest chemical treatments of conventional fruit and vegetables (Couey, 1989). Much of the research still concentrates on its use on tropical and sub-tropical fruit, but some work has been done on apples and pears (see Table 30).

Table 20 Successful heat treatments of apples and pears to control fungal pathogens

Fruit	Pathogen	Heating method	Temp(°C)	Time (min)	Possible injury
Apple	*Penicillium expansum*	Hot water Hot air	45 45	10 15	Reduced storage life Deterioration
	Gloeosporium spp	Hot water Hot air	45 45	6-11 15	
Pear	*Mucor piriformis*	Hot water	47	30	-
	Alternaria tenuis	Hot water	47	7	-

Heat can be applied to fruits and vegetables in several ways; by exposure to hot air, to water-saturated hot air (vapour heat), to hot dry air, to infrared radiation and to microwave radiation.

Practical systems have either used vapour heat or hot waters; these are also the most likely forms to be accepted by organic standards.

4.3.2. Hot water to control fungal pathogens

Heat treatments to control postharvest fungal pathogens have mainly concentrated on the use of short term relatively high temperature hot water treatments. Fruit and vegetables usually tolerate temperatures of up to 50-60ºC for 5-10 minutes which is sufficient to control many plant pathogens. The exact temperatures and duration's need to be carefully worked out for each pathogen crop combination or there can be serious injuries to the crop itself. These include: increased water loss, discolouration, increased susceptibility to contaminating micro-organisms and decreased shelf or storage life. Heat needs to be carefully controlled and measured during treatment in order to avoid these undesirable effects. Also, factors such as the maturity of the crop, crop temperature at harvest and the presence of rain affect fungal development and determine the efficacy of heat treatment in preventing disease (Barkai -Golan & Phillips, 1991).

There is research on reducing the deleterious effects of hot water treatments e.g. the use of polymer film wrap to prevent water loss, the addition of non pesticide chemicals (e.g. sucrose) to prevent discoloration but more information is needed before they could be commercially viable (Barkai-Golan & Phillips, 1991). These would need to be considered by the organic standards bodies and may not be accepted.

4.3.3. Hot air to control pathogens and physiological disorders

A drawback of relatively short but high temperature treatments is that their effects are short lived and produce can become contaminated again after treatment. They are also very commodity and pathogen specific. Relatively extended hot-air treatments may be able to overcome some of these problems, and in some ways they are more practical because the crop does not have to be wetted. Wet crops are very prone to pathogen attack and need to be dried off before storage. Prolonged heat treatment at 38ºC for 3 or 4 days can enhance a crops own resistance to disease and induce wound healing responses. The effect of the heat treatment is prolonged making post treatment contamination less likely (Klein & Lurie, 1992).

Prolonged hot air treatments also have the advantage that they can be used to protect against physiological disorders. Research has shown that superficial scald in apples and internal browning in pears can be reduced by prolonged hot air. Firmness and texture of apples can also be increased by heat treatments (Lurie & Nussinovitch, 1996, Klein & Lurie, 1991). Susceptibility to chilling injury can also be moderated so that crops which normally suffer chilling injury can be stored together with other crops at lower temperatures.

4.3.4. Conclusions

At present research and technology on heat treatments is a long way from providing practical solutions for organic and conventional crops. However, it is still a promising technology, especially for a wide range of problems associated with storage of top fruit.

A major drawback will be its cost. Heat treatments require extra equipment and will require substantial amounts of energy to run.

Prolonged hot air treatments delay storage by 3 or 4 days which will present logistical difficulties while the store is being loaded. Also hot fruit entering a cool store will put substantial strain on the cooling system, although this could be overcome by using hydrocooling for some crops. As the technology develops evaluations will need to be made as to whether the benefits outweigh the costs.

4.4. ESSENTIAL OILS AND OTHER PLANT EXTRACTS

Some naturally derived pesticides are permitted by organic standards. It is essential that any new substances are safe and effective. Any pesticides used in organic agriculture are subject to the same PSD regulations as conventional pesticides.. There will probably be some resistance to the inclusion of more pesticides of a chemical nature to the permitted list of substances by UKROFS.

There has been a lot of recent research on naturally derived pesticides such as essential oils. e.g. Caraway, Spearmint, Cumin and Cassia have been shown to suppress the growth of fungi causing storage losses in potato. *Fusarium sulphureum* (dry rot), *F. solani* var. *coeruleum* (dry rot), *Helminthosporium solani* (silver scurf) and *Phoma exigua* var. *foveata* (gangrene) were reduced for up to three weeks (Gorris *et al.*, 1994). Their effects tend to be relatively short lived and their application is more likely to be of use in tropical countries to prolong short term storage where cooling is not available.

The essential oil of caraway seed is also known to suppress sprouting in potatoes. A recently released sprout suppressant carvone (traded as ‘Talent’), derived from caraway essential oil, has been shown to be effective (Briddon, 1995). Unfortunately it is not permitted for organic use as it contains synthetic derivatives.

4.5. BIOLOGICAL CONTROL OF POSTHARVEST DISEASES OF FRUIT AND VEGETABLES

4.5.1. Introduction

In principle the use of biological control agents is acceptable in organic production but any that have been genetically manipulated are not. In future this may limit the number of products suitable for organic registration.

Advantages

There are a number of advantages to using biological control treatments after harvest rather than in the field during crop growth.

- The amount of product required is relatively small and easy to apply.
- They can be applied along with substances which enhance the activity of the product e.g. nutrients.
- The store conditions can be manipulated in favour of the biological control agent e.g. temperature, relative humidity and carbon dioxide and oxygen levels in controlled atmosphere.
- If it is undesirable to have micro-organisms or their residues on the crop they may be removed after storage. e.g. apples are often emptied into water filled conveyors. Mild disinfectant could be added to the water to remove most of the organisms.
- Mixtures of biological control agents can be used to target a range of storage diseases.

Disadvantages

There are a number of important drawbacks with using biological control agents.

- Consumers may object to ‘contamination’ of produce with micro-organisms.
- The 1990 Food Safety Act does not distinguish between biological control agents and pests.
- Some antagonists, especially bacteria, which have been selected for postharvest use produce antibiotics. The survival of the antagonist will depend on several factors making it impossible to predict how much antibiotic is present on the crop. Micro-organisms which produce antibiotics are unlikely to be accepted for organic use.
- The mode of action of the biological control agent needs to be fully understood before it is put forward for registration. This requires considerable research effort.
- All new postharvest pesticide products are subject to the Control of Pesticides Regulations (COPR). Evidence has to be provided that they are safe to use and effective. On top of this the cost of registering a new postharvest product with the Pesticide Safety Directorate is in the region of £64,000. The potential market is small for postharvest pesticides.

- At present biological control agents are applied in liquid form. Of the crops considered in this review, only apples, pears and cabbage are likely to be suitable, unless alternative formulations are developed.

4.5.2. Research

In the UK little research has been focused on postharvest biological control, but in other parts of the world particularly in the USA and Israel, research is more advanced and some commercial products are already available (Koomen, 1997).

In general bacteria or yeasts have been selected as potential postharvest biological control agents and their use to control pathogens of fruit is most commonly researched (Koomen, 1997), but there are also research efforts for use on cabbage (Leifert *et al.*, 1993; Stanely *et al.*, 1994) potato (Colyer & Mount, 1984; PMB, 1996) and carrots (Tronsomo, 1993). A comprehensive summary of research on biological control agents, their target pathogens and the crops they have been tried on is reviewed by Droby & Chalutz (1994).

4.5.3. Commercial preparations

There are no postharvest biological control agents available in the UK or Europe, but two yeast preparations are available in the USA, 'Aspire' and 'Biosave'.

'Aspire' contains *Candida oleophila* and is marketed to control *Penicillium* spp. and *Botrytis cinerea* on apple. These two fungi result from postharvest infection, unfortunately the most common postharvest diseases on conventional apples in the UK originate from preharvest infection (Berrie, 1992). 'Aspire' has been trialed by Colgan (1996) on conventionally grown apple cv. Cox in five months of controlled atmosphere storage. Only *Botrytis cinerea* was significantly reduced. Other storage rots were unaffected. Unfortunately, the most important storage diseases on conventional UK apples were not controlled.

The active ingredient of 'Biosave' is the yeast *Cryptococcus laurentii*, again this is marketed to control *Penicillium* spp. and *Botrytis cinerea.* As far as is known it has not been trialed in the UK.

4.5.4. Conclusions

Postharvest biological control in organic systems is of potential benefit, but the technology is still developing. The commercial preparations already available in the USA do not seem to control the major storage pathogens of UK conventional apples, however the disease profiles of organic fruit may be different, so separate trials may be worthwhile. The use of these products on other crops also needs to be explored. Biological control agents which are applied preharvest to control storage rots caused by fungi which infect before harvest are likely to be of benefit because these are the rots which are most common in UK stored fruit.

The mode of action of any potential biological control agents needs to be well understood as biological control agents which produce antibiotics are unlikely to be accepted for organic use and neither are those which have been genetically modified.

4.6. RAPID DIAGNOSTIC TESTS

There is considerable research effort at present to develop rapid tests to diagnose and estimate disease levels in a wide range of crops. These are likely to be of direct benefit for predicting whether it is worthwhile to attempt to store a particular crop and for how long. As these tests become available there may be some requirement for development work specifically for organic crops. Without the use of pre and postharvest pesticides predictions of 'storage potential' from initial inoculmn levels may need to be adjusted.

5. STORAGE OF ORGANIC CEREALS

5.1 SUMMARY

Analysis of financial and market prices available (only 1.5 years data) revealed that the costs of storage could be covered but it was not profitable for all cereals and for all forms of storage. It would be far more satisfactory to base conclusions on 5-10 years of economic data but this information has not been collated for organic grain. The individual circumstances of some organic farmers means that some do make a profit from storing organic grain if they can sell at the right time.

Despite the pessimistic economic analysis, growing grain without storage is not recommended, some form of storage is essential. Approximately 90% of farmers growing organic grain do so for their own livestock feed and require storage over the winter period. Storage is also essential for organic grain intended to be marketed for human consumption. Without storage farmers face considerable financial risk as they may not find a buyer for their grain, or have to accept a low price from millers at harvest time.

Co-operative stores are a possible solution but at present there are very few co-operatives where organic grain can be segregated from conventional, this can also be a problem for farmers storing their own grain during conversion.

The main technical problem for storage of organic grain is the cleaning of the store and its associated equipment. The use of store fumigants and most products available e.g. pesticides, to clean stores, are not permitted by organic standards. If the store is free of pests prior to loading, and good management and hygiene is practised, organic grain can be stored successfully using existing approved organic practice and storage equipment available on the market. However, storage of organic grain does entail more risk than storage of conventional grain as there is no option to treat with pesticides if problems do develop. Pests and fungal diseases can only be avoided, but this can be achieved by drying the grain to 14% moisture content and reducing its temperature to 10ºC or below.

Short term storage (up to 2 months) of feed grain does not require specialist facilities as long as the grain is below 16% moisture content. Access to a grain drier is recommended as the grain may not dry naturally to this moisture content by harvest, in any case, if the grain is destined for sale it needs to be dried to 15% moisture content. In some years and in some areas of the country grain may dry naturally to as low as 14% by harvest, but in the British climate this is notoriously unreliable. Delaying harvest of milling wheat until 14% moisture content is reached is not recommended as there is a significant risk of decline in the Hagberg Falling Number. Grain drying is therefore essential and cooling the grain as it comes off the combine is also beneficial even for short term storage.

For storage over winter, the grain must be dried to 14% moisture content and preferably cooled to 10ºC or below. Cleaning of the grain, ideally before drying or just before storage (although not often practised by organic farmers) is encouraged. Ambient air cooling should be sufficient for on farm organic storage from harvest until May. At present there is little need for organic grain to be stored beyond this time. Demand is such that most organic grain has been sold off the farm by May or June. In any case it is recommended that on farm stores are cleaned and left empty for three months to ensure the store is pest free before the next crop is loaded in August.

Long term storage (2-3 years) is only required where there is over production of cereals. This is not a likely scenario for organic grain in the near future. The demand for organic feed grain is set to increase with the tightening of organic feed standards required by UKROFS. If over production did occur, technology is available to achieve long term storage. As long as the grain has been cleaned and is kept dry with ventilation, organic grain has been stored for up to 2 years. However, it is recommended that long term storage will require specialist systems with a high level of monitoring and resources to re-dry and cool grain.

It is not realistic to make a blanket recommendation for a particular storage system for organic grain. Drying and storage systems need to be individually costed, tailored to the farm, the end use of the grain, the length of storage required, and the finance available. Although certain design features of buildings, dryers, bins and conveyors which enable easy cleaning are an important consideration.

The most useful research areas for storage of organic grain would be:

- products and techniques for cleaning the store
- cost effective, energy efficient drying, including low volume air extraction techniques and the development of renewable energy sources (e.g. solar drying)
- seed health e.g. techniques for storing organically raised disease free seed and diagnostic kits for detecting fungal contamination on seed
- rapid detection of pests and fungal diseases in stored grain.

Other areas of limited interest which are being covered to a certain extent by research for conventional production either in the UK or abroad include, controlled atmosphere for long term storage of grain and biological control of pests.

5.2 CURRENT PRACTICE AND PROBLEMS

Growing organic grain without storing it is not considered profitable (Starling, 1997a). Approximately 90% of organic cereal farmers grow grain for their own livestock feed and require storage over the winter. Storage is also required where the grain is to be sold. Some organic growers still rely on selling their grain directly from the field but this practice bears a considerable financial risk. Millers and processors may not be able to take the crop at harvest, and it may not fetch a favourable price. Consequently most organic cereal growers store their grain, at least for a short period of time.

The practice of storing grain temporarily on an uncovered hard surface no longer complies with food hygiene standards because it is open to vermin such as rats, mice and birds. The 1990 Food Safety Act states that grain stores must be free from such pests. There is continual pressure on the farming and food industry to improve and assure the conditions under which food is produced. In response, the NFU launched a voluntary farm assurance scheme for combinable crops during 1997. Grain storage is an important issue in the scheme which endeavours to provide criteria for storing grains in an acceptable manner. Many farm grain stores, whether for conventional or organic cereals will probably not meet any future legislation without some upgrading (RASE & Thornton, 1997).

The main constraints on organic farmers buying designated storage bins, silos or buildings are ones due to economies of scale. Often an organic cereal grower is operating on a mixed farm or grows a fertility building crop so that not all of the land is down to cereals at any one time, several different cereal crops are grown in the rotation, and organic yields tend to be lower than conventional. The result is that relatively small quantities of different types of grain need to be stored separately making designated storage buildings harder to justify financially when starting from scratch. At the other end of the equation, a conventional cereal farmer with existing storage converting to organic production can end up with excess storage capacity.

Co-operative storage could provide a solution but there are few co-operatives which can segregate organic grain from conventional. Segregation of grain during conversion for farmers storing themselves, can also be a problem.

As far as the technical success of storage is concerned, storage of organic grain is not generally perceived as a problem, either by farmers or grain merchants handling the grain. Effective store cleaning can be a problem but apart from this the main problems associated with the storage of organic grain are those which are also experienced by conventional farmers i.e. existing facilities need to be updated to keep pace with current technology. A small but increasing number of organic crops have been found with mite infestations and there has been the odd case of grain weevils

(Starling, 1997, pers. comm.). Most storage problems can be avoided with good husbandry and forward planning. Drying grain to below 14% moisture prevents mould growth and minimises the risk from most mites and beetles. Cooling the grain by aeration to below 10°C further reduces the risk of storage problems. Grain for feed can be stored at much higher moisture contents (up to 22-24%) in airtight silos or bins.

5.3. TECHNICAL ASPECTS OF ORGANIC GRAIN STORAGE AND GOOD PRACTICE

5.3.1. Conditions for storage.

Like other crops, grain is still alive and biologically active after harvest. The grain continues to respire during storage giving off heat and moisture as waste products. Ideal storage conditions reduce respiration to a minimum by reducing the moisture content and temperature of the grain. The same conditions also minimise risk from insect pests, mites and moulds. Reduced levels of oxygen which halts respiration can also be utilised where it does not matter if the grain is dead e.g. for livestock feed.

Hot spots are a major source of problems in stored grain, the higher the temperature and moisture content of the grain going into store the more risk there is of hot spots developing which in turn lead to higher biological activity, elevated temperatures and moisture being released. The moisture tends to move up through the grain pile and condenses in the cooler layers near the surface of the pile. The grain in these layers can then visibly sprout, and mould, insect and mite infections can take hold.

The surface of any bulk stored grain (except for grain in closed bins) is also likely to absorb moisture from the air. The increase in moisture will only affect a layer of about 2-3 cm but it will attract mites, moulds and fungus eating beetles and booklice. Scavengers such as spider beetles and house moth larvae follow. Predatory beetles and mites may also arrive to feed on everything else and although they don’t directly damage the grain themselves they can still cause grain to be rejected at the millers.

Traditional methods of on-farm storage generally rely on controlling the moisture content, and to a certain extent the temperature, of the grain going into storage. Without proper conditioning facilities it is unwise to attempt to store the grain for longer than 5-8 weeks (Kelly, 1996). Table 31 gives and idea of the expected storage life for mould free barley:

Table 31 Expected duration of storage at different temperatures and grain moisture content before barley will show moulding.

Moisture content (%)	Temperature °C	Expected storage life (weeks)
26	25	0.2
18	20	2
18	15	4
16	20	12
16	15	30
16	10	50
16	5	120

(ADAS, 1985)

Over time, various changes and infestations can be expected in stored grain. Table 32 summarises the problems in bulk stored grain.

Table 32 Pattern of changes in stored grain with respect to insect and mite pests

Months after harvest	Changes at grain surface	Pest succession
0 -2	Slight moisture content increase. Bulk releasing heat	No increased risk
2-4	Moisture content up by 1 -2%. Temperature of grain stable. Diurnal temperature fluctuations at the surface.	Pest mites arrive. Mould if > 15% moisture content. Fungus beetles & booklice
4 - 7	Moisture content variable 2 -3 % increase likely. Occasional daily heating depending on weather and roof construction.	Mite, fungus beetle & booklice established. Spider beetles and house moths arrive.
7 -12	Gradual lowering of moisture content with drier weather conditions. Slow increase in bulk temperature.	Mites, fungus beetle, booklice, spider beetle, house moth, predatory mites and beetles.

For storage of more than 2 months the grain needs to be dried and there should be a system of blowing ambient air through the grain store to cool it. Using cool night air is appropriate from July onward in the UK (HGCA, 1992). Temperature changes should be monitored on a weekly basis and traps should be used to monitor the arrival of mites and insects. If any pests are detected in organic grain that cannot be cooled, steps should be made to sell it before the infestation gets out of hand.
A comprehensive study by Burges & Burrell (1964) on storage conditions for grain still forms the basis for storage recommendations for grain provided by Farm Electric (b). The following general points are useful:

- Even at 16% moisture content temperatures as low as 4°C are required for safe storage through the winter.
- No grain should be stored that is at a temperature of more than 15°C. Grain that is coming off the combine is usually above this and needs to be cooled.
- To be absolutely sure that there is no mite risk moisture content should be below 12% and grain temperatures during storage should not exceed 3°C. In practice this is hard and expensive to achieve. A moisture content of 14% combined with a grain temperature in store of 10°C is now recommended for prolonged storage as this combination inhibits the activity of the majority of mites, insects and moulds (Kelly, 1996). (However, under these conditions,

good hygiene and monitoring of temperature, humidity and pests, cannot be over emphasised for organic grain where fumigation or the use of chemicals is not an option if problems develop.)

- Not all damage to grain is visible to the eye. Moulds and even mites and insects can be hard to detect, the store should be closely monitored and inspected frequently.
- Damaged grain, fragments of green material and chaff can reduce storage life and although many farmers successfully store grain without cleaning, it is beneficial if long term storage is intended.

Seed grains and those destined for malting barley need special care to avoid losses in germination and viability. Malting barley may need a period of warm storage to ensure dormancy is broken. During this time risk of pest infestation is high. The home grown cereals authority has funded research on modified or reduced oxygen atmospheres to store malting barley. The studies showed that malting barley can be stored successfully in low oxygen atmosphere for up to six months without detriment to germination or recovery from dormancy and it provides an alternative to the use of insecticides, fumigants or low temperature storage (HGCA, 1991)

5.3.2. Store cleaning

Storage pests are adapted to a dry indoor environment and are not normally found in the field although they can wander away from stores at times of population explosion. In order to infest a store they have to either have persisted in the store from the year before or brought onto the farm by infested grain lorries, contaminated pallets of feed arriving from the mill, second hand machinery or in grain brought from another farm for storage or drying, clothing, brushes and equipment . Do not let lorry drivers clean out their grain vehicles on your farm, lorries should be cleaned at least half a mile from the nearest grain store. Do not keep sacks of feed in the grain store and on farm feed mills should be cleaned and the debris burnt (Kelly, 1996).

Before the new seasons harvest is brought in the store should be thoroughly cleaned. The design of the store, dryer, conveyor etc. with respect to cleaning is an important point to consider when choosing equipment. Effective cleaning helps to prevent rodents, birds, insects and mites. It is important to do this several weeks before the store is to be used to break the life cycle of any insect pests. (Ideally grain should not be stored on farm after the end of May (Starling, 1997, pers. comm.). Insect baiting traps such as ‘pitfall cones’ can be placed in the clean and empty store to reassure that the store is pest free.

Fumigation to clean the store is not permitted by Soil Association standards. Cleaning the store should be by scraping, sweeping and/or vacuuming until no dirt or crop residue can be seen. This includes all crevices, rafters, dryers, elevators, conveyors, ventilation ducts, under ventilated floors, behind grain walling, holding bins and overhead hoppers. The combine and trailers should also be cleaned as well. Protective clothing against the dust should be worn, especially a face mask. Contractors can be used for store cleaning but the farm staff are more likely to know where likely trouble spots are. If necessary equipment should be dismantled. The debris should be burned, not placed in a dump out of site or all the high labour costs will be wasted when any pests in the dust simply return to the store.

5.3.3. Monitoring for insects and mites.

Not only is it important to monitor organic grain during storage it is also important to monitor the cleaned store before storage to ensure a good job has been done. Storage mites and insects are hard to detect visually, being small (<2mm), mostly dull brown, and are only active at night. Detection by the collection and assessment of samples proved unreliable in HGCA funded work (HGCA, 1992). More reliable and sensitive traps have been developed and are commercially available. One of the most useful is the PC trap or ‘pitfall cone’ which can be used to monitor both the store and the grain bulk. Most traps can only be used in one of these situations. Essentially the PC trap is a cone with a domed perforated cover. The internal rim of the cover is coated with PTFE to prevent the escape of insects and mites. Pests ‘blunder’ into the traps but their effectiveness can be increased by placing pheromone baits inside.

At each monitoring point within the grain bulk a trap should be placed on the surface and another approximately 30cm below the surface. Guidance on the number of traps required for your situation should be sought from suppliers. Approximate prices of pitfall traps are £65 for a box of 20 (Martin Lishman, 1997). It is important to correctly identify the insects and mites present or unnecessary and costly action may be carried out or a serious pest ignored. If in doubt it may be worth enlisting the help of a professional entomologist. The Home Grown Cereals Authority (1996) has recently produced a very useful handbook ‘Grain storage to avoid infestation’ costing £3 which contains photographs, descriptions and storage regimes to control the major beetles, weevils and mites which occur in grain.

5.3.4. Action to be taken if insects and mites detected in grain.

There are a number of non-chemical control methods available to organic farmers (see Table 33). Good management, hygiene, monitoring of temperature, humidity and of pests are all essential for the strategies to work. If cooling or grain drying equipment is not available, the temperature of the grain is above 15ºC or the moisture content is above 15% it is best to sell the grain as quickly as possible.

Table 33 Controlling mites and insects

Option	Where applicable
Lower grain temperature below 10ºC.	Any grain pest insect e.g. weevil, beetle
Lower grain temperature below 5ºC	All mites
Re-dry grain to below 14% moisture content	All mites
Turn the grain through a long conveying run.	Quick clean up of mite infested grain
Convey grain through a cleaner-auger	All mites, high proportion of some beetles but won't clean up weevil larvae
Lower the grain to below 0ºC for few weeks	Kills most pest grain beetles

(Adapted from Kelly, 1996)

Equipment is available to treat 'hot spots'. A hollow lance can be inserted into the grain and cool dry air blown through it (Martin Lishman, 1997) (However, no standard recommendations could be found for using this method in FarmElectric or HGCA publications).

5.3.5. Monitoring temperature, humidity and grain moisture content.

Good storage management relies on regular and effective monitoring. The Farm Energy Centre at the National Agricultural Centre can provide lists of suppliers of a large range of storage equipment from the store itself, fans, dryers and monitoring equipment.

5.3.5.1 Sampling methods

In order to assess grain moisture and other aspects of quality a sampling strategy is required which ensures that they are representative of the batch from which they are taken. Unfortunately there is little scientific basis to the way a lot of sampling equipment has been designed and although sampling strategies are well defined the accuracy of the results has not been clearly established. HGCA (1992) has funded work to address this problem but there is still a long way to go to provide sufficient scientific basis to a British Standard method of sampling grain. So far the work as revealed that quality including moisture content varies greatly within a grain bulk and so that variations between single samples could have significant financial implications for both buyers and sellers of grain. Several samples should be taken from a grain bulk, preferably from different depths, and measured separately to get a representative picture.

The current guidelines on sampling grain produced by FarmElectric (b) are as follows: Several samples are needed, each sample should be composed of a handful of grain from several parts of a field or trailer bulked together and divided into about 0.5 litre lots. Three or more determinations should be made from each lot. The results can then be averaged. Alternatively, each original handful sample can be tested three times and an average calculated. This has the advantage that a picture of the variation in moisture content across the field can be built up. Samples which are not tested immediately should be stored in airtight containers or knotted plastic bags and kept away from extremes of temperature.

There are various grain sampling probes available to sample at different depths within a grain store, these cost in the region of £69 to £145 (Martin Lishman, 1997) depending on the type. As yet there is no evidence to suggest that any particular type i.e. Gravity spear, compartmented spear or vacuum spears give more representative samples than another (HGCA, Report 34). It is the number and way that samples are taken which is most important.

5.3.5.2. Grain moisture content

The most accurate way to measure grain moisture content is to accurately weigh a sample place it in a constant temperature aspirated oven and then weigh the sample again several hours later when it is completely dry. This is a method confined to the laboratory, therefore, there are various grain moisture meters available for use on the farm. Some require the grain to be ground, and they tend to be accurate to within ± 1-1.5% of moisture. It is important that any meter is correctly calibrated and checked. If the meter relies on measuring grain conductivity then grain grown on soil of high iron content will have greater conductivity than grain from a low iron soil and this can cause error. Other factors including variety, fineness of grinding, surface wetness of the grain, moisture level of the grain and air temperature can all affect the accuracy of the meter.

Prices of grain moisture meters vary tremendously and some systems can also measure grain temperature. Portable units which do not need to weigh the sample (although they do need grinding) and automatically correct themselves to take into account the temperature of the grain are available from 'Protimeter' for around £265-590.

5.3.5.3. Measuring relative humidity

It is important to be able to measure the humidity of air drying grain as moist air will not be effective. It can also be useful to measure the humidity of the air in the store. Often hygrometers can be used in a range of situations e.g. in a vegetable store. Some are portable and can be hand held whilst others need to be wall mounted and some can take temperature readings (Prices are in the range of £55-100)

5.3.5.4. Measuring temperature

There is often a need to measure the temperature of the grain bulk. Any sudden rise in temperature is an early and sensitive warning that problems are developing in the store. Remote and direct reading is available and is usually either of the thermo-couple or thermistor type and cost in the region of £50-110 (Martin Lishman, 1997). They must be calibrated correctly and used according to the instructions.

5.3.6. Preventing and controlling rodents

The most commonly found rodents in farm grain stores are the brown sewer or Norway rat (*Rattus norvegicus*) and the house mouse (*Mus domesticus*). Specialist guidance should be sought for the prevention and control of other animals including rodents which may be protected under the Wildlife and Countryside Act. Prevention is better and cheaper than cure once the vermin is present the grain is already contaminated (Kelly, 1996).

Prevention

Keep the store and surrounds clean and in good repair. Grain spills outside the store can attract rodents in. Adjacent trees and bushes should be cleared back as these provide shelter and a means of accessing the building. Stores can be proofed against rats. Repair doors, windows, down pipes (these should have internal gauze baffles and external guards), wall sheeting (especially at ground level), edges to concrete aprons and plinths. Rats can squeeze through holes about 14mm in diameter while mice can get through an 8mm gap and are harder to exclude. The store should be carefully monitored for both pests especially as the winter approaches. For mice it may be necessary to keep permanent poison bait points when there is a threat of mouse invasion. For rats an external barrier of bait points may be appropriate before they breach the proofing on the store (Kelly, 1996).

Control

Before planning a control exercise the extent of rodent infestation should be monitored. For rats baiting with a known quantity of un-poisoned soaked wheat or other attractive food which they are used to eating is suitable. The number of rats can be estimated by the amount of grain taken. It is important the bait is left out for several days rats take some time to become accustomed to new foods. Non-poisoned wax blocks are available for assessment of mouse populations. Mice feed little and often so a large number of wax blocks is necessary to get a good estimate of the population size (Kelly, 1996).

Only when the population of rats/mice is known should control methods be contemplated. Organic control methods include ultrasonic repellent devices, cats, traps and some rodenticides. Ultrasonic repellent devices are considered ineffective. Cats only have a minor impact on populations, can actually bring rats and mice into the store and can leave their own contamination. Traps can be effective for small populations but need to be used at high densities. Static bait traps using licensed poisons for controlling rodents are permitted under UKROFS standards (4.706) provided there is no risk that the stored product can be contaminated or the poisons eaten by other animals or wildlife. The bait trap is not a true trap it just contains the bait in such a way that other wildlife can not access the poison. The poison and bait must be stored under lock and key away from food. As yet the use of rodenticides forms the basis of a comprehensive control strategy but must be applied selectively, effectively and with great care so that non-target animals are not affected. Baiting patterns and intensity should be followed according to the labels recommendations. The commonest cause of control failure is inaccurate estimation of the size and range of the rodent population and insufficient bait and time to ensure complete control (Kelly, 1996).

Anti-coagulant rodenticides which have a chronic effect (i.e. a small amount is eaten over several days to be effective) are considered the most effective for rat control. These include: Warfarin, Diphacinone, Chlorophacinone, Cocumatetralyl, Difenacoum and Bromadiolone. Brodifacoum and Flocoumafen can also be used but they are not cleared for outdoor use.

Chronic rodenticides can take some time to be effective, disruption of harbourages and the food supply will be needed at first (Kelly, 1996).

For mice calciferol is an effective acute pesticide if resistance to the above poisons is encountered (Kelly, 1996).

Before using rodenticides local knowledge of resistance to the various poisons should be sought. Resistance to first generation anticoagulants are common in central Wales, Berkshire, North Hampshire, East Wiltshire, South Oxfordshire, Sussex and Kent. Resistance to difenacoum and bromadiolone (second generation anti-coagulants) is also widespread in central southern England (Kelly, 1996).

5.3.7. Preventing and controlling birds

Birds are very heavily protected by UK and European legislation. Feral pigeons (*Columba livia*), house sparrows (*Passer domesticus*) and starlings (*Sturnus vulgaris*) are the most common bird pests in stores and these are permitted to be killed provided the technique is approved. No control action should ever be taken before checking on its legality. However, shooting a few birds may help in some situations but preventing entry is the most effective policy (Kelly, 1996).

Prevention

Block all possible entry points to the store such as under the eaves or gutter, the door tops and broken windows. Grain should be cleaned from around the outside of the store, birds like to nest close to where they feed. Doors should be kept closed when no-one is working in the store as it should be kept as dark as possible, which tends to make the birds feel insecure. Netting can be used to prevent access, suitable mesh sizes are:

Feral pigeon	50 or 38mm depending on species
Starling	28mm
House sparrow	19mm

There are also anti-roost devices available. One of the most common being the ‘Bird Wire System’ which uses suspended wires running along the roosting surfaces (Kelly, 1996).

5.3.8. Moulds and mycotoxins in grain, prevention and control

A number of yeasts and fungi can be found in stored grain. The most important of which are the fungi *Fusarium, Aspergillus* and *Penicillium* spp. because they produce mycotoxins. Some fungi of the *Aspergillus* spp. produce aflotoxins which are types of mycotoxin that can be passed down the food chain i.e. the meat from livestock fed with contaminated grain contains breakdown products which are toxic or carcinogenic to man (Lacey *et al.*, 1991).

Infection with *Fusarium* develops in the field and persists in storage but does not usually spread further. A*lternaria* spp are also found in stored grain and again this first infects during crop growth but it is not considered as important as *Fusarium*. Both these fungi require high relative humidities i.e. free water in the grain, therefore they do not usually develop in store. *Aspergillus* and *Penicillium* species develop only once the grain is in store (Lacey *et al.*, 1991).

As well as producing mycotoxins fungi or moulds in grain can cause heating (sometimes to the point of ignition), losses of dry mater, discoloration of grain, odours, loss of germination, caking, reduction in baking quality and alter digestibility. The fungal spores of moulds can also cause respiratory disease hazards to exposed workers.

Without the option of fumigation and fungicide usage it is feared that organic grain may contain higher levels of mycotoxins than conventional grains. Studies at the Scottish Agricultural College (D'Mello & MacDonald, 1995) to assess the potential levels of mycotoxins in UK organic wheat and oats were considered inconclusive. The grain tested was of satisfactory mycological quality but the trials were carried out during 1991 which was a dry year and there was little fungal disease on cereals anyway.

Many storage moulds are intolerant of conventional fungicides (Lacey, 1990) and there is little evidence that current fungicides control *Fusarium* ear blight during crop growth. The chemicals available for pre-harvest and postharvest control are limited for conventional agriculture and storage. Research has been carried out on non-chemical methods of control. One of the most effective is to reduce the moisture content of wheat to below 14.6 %, and barley to below 13.6% for long term storage of 2-3 years (Lacey, 1990). More effective control can be gained by using a combination of reduced moisture content and reduced temperature so that optimum storage conditions need not be so extreme. The combination of reduced grain moisture (14%) content and temperature (10ºC) used to control insects and mites also prevents moulds developing (Soffe, 1995). Manipulating the humidity of the air in the store and the composition of the gases in the air between the grains can also reduce risk from mould. Temperature in the store should remain as stable as possible as alternating cool and warm temperatures can actually enhance mycotoxin production by storage fungi such as *Aspergillus flavus* and *Fusarium* spp. (Lacey, 1990).

5.3.8.1. Fusarium *spp.*

Fusarium infection of grain occurs before harvest but it is possible that toxin production can continue in store if conditions are suitable. The amount of infection in the field depends upon weather conditions during crop growth especially if there is rain at anthesis, lodging and persistent rain prior to harvest. *Fusarium culmorum* is a soil borne fungi and is considered a competitive saprophyte persisting in soil and in crop debris such as stubble for up to two years. Crop rotation and deep ploughing to bury debris are considered as useful control measures (Jones & Clifford, 1978). Organic growers practice crop rotation which may explain why it is not considered as a particular problem of organic grain. However, grass is also a host and many growers use grass clover leys in their rotations, they also tend to shallow plough and in theory they could run into problems but this does not seem to be borne out by experience. It is mere speculation but a possible hypothesis is that increased microbial activity claimed to be present in organic soils may be suppressing the fungus.

F. culmorum can also be seed borne but this is considered to be only a minor source of infection. Conventional seed can be treated. It would be prudent for organically raised seed to be tested to make sure it is clear of other seed borne diseases as well as *F. culmorum.*

F. graminearum is also found in stored grain and it is this species that is best known to produce mycotoxins. It affects oats, barley, wheat and rye. Again it infects the grain at flowering and is favoured by wet, cloudy weather. The affected ears appear to ripen early and the fungus can form a pinkish mass of mycelium on the ears. What is more difficult to detect is grain which is infected but has no outward signs. The grain would need to be tested for its presence using traditional agar plating methods. However, rapid immunoassay techniques are being developed to detect *Fusarium* spp. (HGCA, 1992). *F. graminearum* like *F. culmorum* is soil borne and crop rotation and deep ploughing are considered worthwhile control measures. Seed testing and the use of resistant varieties are also important prevention measures.

Varieties of winter wheat listed by NIAB with good levels of resistance to *Fusarium* ear blight (NIAB, 1997c) are Consort (7), Hereward (7), Spark (8). Scores are from 0-9, 9 is highly resistant. Information on resistance in spring wheat, barley and oats is not available on NIAB recommended lists at present. More readily available information on the resistance of varieties to storage diseases would be useful.

5.3.8.2. Aspergillus and Penicillium

Apergillus and *Penicillium* species are true storage moulds in that they only invade once the grain is in store. The source of spores arrive on the grain before harvest and further contamination and spread of spores can occur from the air and contaminated grain during threshing. A few species can invade grain at quite low moisture contents e.g. *Aspergillus restictus* can invade wheat at 13.8-14.2% (MC) (Christensen, 1991), but they can be controlled by a combination of low moisture content and temperature.

Aspergillus and *Penicillium* usually develop where the grain has been stored too wet and are most common where the grain is destined for animal feed and has been stored moist in supposedly airtight silos. The most common causes of storing the grain too wet are inadequate drying, inaccurate moisture meters or poor sampling techniques when measuring the moisture content of the grain. Chemicals such as propionic acid (not permitted by UKROFS) are added to conventional moist stored feed grain to prevent mould growth, but if they are not applied at the right rate or not mixed in properly they are ineffective. There is even evidence that low doses of propionic acid can actually enhance aflatoxin production by *Aspergillus flavus.*

Methods to detect moulds are very laborious, as a result rapid immunoassay methods are being developed to detect *Aspergillus, penicillium* and *Fusarium* in cereal samples (HGCA, 1992).

5.4. DESCRIPTIONS AND COSTS OF GRAIN STORES AND DRYING EQUIPMENT

5.4.1. Cleaning

Existing organic farmers successfully store grain without cleaning it first, however despite the considerable extra expense, grain cleaning should be encouraged because chaff and debris can cause uneven drying and 'hot spots' of insect, mite and fungal infection in stored grain. Cleaned grain will also ensure that no penalty for a high proportion of 'screenings' will be charged by millers and merchants. It is advisable that farmers with over 50 acres of grain should clean it before storage, and certainly before it is sold, as cleaning by the merchant can be costly. Hire of cleaning equipment or the use of a mobile contractor may provide an option.

5.4.1.1.Pre-cleaning

Ideally the grain should be cleaned before drying so that bits of debris are not unnecessarily dried. There are several different types of 'pre-cleaners' which basically consist of a separator which may include sieves as well as air suction to remove straw and debris from wet grain prior to drying. The through-put at which the cleaner can operate will affect loading and in some cases it is more practical to clean after drying but before storage. Auger-cleaners are usually the cheapest but can only do minimal separation an additional aspiration unit at the outlet of the auger would be required to remove straw, chaff and other light impurities. A double sieve with an aspiration unit produces a cleaner sample but is also more expensive (ranging from £4,313 -11,706 depending on the through-put, BDC Systems Ltd, 1997).

5.4.1.2.Cleaning

To gain a commercially acceptable sample and to achieve more precise grading for seed 'cleaners' are required which produce a better sample than pre-cleaners. They are usually more expensive but can often be used for pre-cleaning the grain as well if run at a higher output. Prices start at around £5,645 for a rotary screen cleaner without aspiration, and £7,393 for a rotary screen cleaner with aspiration (BDC Systems Ltd, 1997). Cereal sieve cleaners start at around £5,325 (BDC Systems Ltd, 1997).

5.4.2. Drying

A study carried out by AFRC Engineering and ADAS (FarmElectric, d), where the performance of different grain dryers were modelled over a 20 year period, indicated that conventional wheat could only be consistently dried down from 20% moisture to 15% moisture if the dryers had some form of heat or dehumidification. If ambient air only was blown through the crop drying would only be successful in 4 years out of 20. If the dryer was only used when air temperature and humidity were suitable then drying would be successful 16 years out of 20. The running costs of dryers which used electricity to heat the air were more expensive (£3.47/t for every 5% decrease in moisture) than LPG gas burners (£2.93/t). Using off peak electricity only reduced the cost to £2.75/t. Dehumidifiers were the cheapest ranging from £1.60 to £2.40/t but the initial capital outlay of these systems is high (see section 5.4.2.5)

Where drying is required there are five basic systems:

5.4.2.1. Under floor drying.

This usually consists of a single span building with a central tunnel, fans, gas burner and under floor ducting. The addition of stirrers facilitate more effective and quicker drying. The central tunnel splits the store enabling two varieties to be stored separately. With this type of drying the grain can be tipped quickly into the store at harvest time resulting in low labour and machinery requirements for grain carting. Costs are kept reasonably low since the functions of drying and storage are combined, but it gives a slow drying rate of 0.5% moisture per day or less, and its successful operation requires a high level of management (Bomford, 1995). Heat should not be used to dry grain above 18% moisture content (MC) as it results in condensation forming in the upper layers of the grain. Drying rate and efficiency are increased if the store is filled in layers rather than piling it all up in one corner. If the grain is above 22% MC it should not be piled more than 1m deep or the grains may become crushed and drying time will be increased.

The main disadvantage of this system is that drying takes several weeks and the warm grain is very attractive to most pests. The grain should be monitored very carefully using 'pitfall cone' traps to detect any onset of pests. The temperature of the grain should be monitored carefully both during drying and during storage this helps to detect problems before they develop. The other disadvantage with this method is that large volumes of humid air are blown out of the grain and water can condense onto the structure and drip into the grain causing problems.

5.4.2.2.Continuous flow drier.

Damp grains can be put through a drier before entering the store. Once dry the grain should not need ventilating during storage, but a low volume ventilated floor in the store would be an advantage. Loading the store is slower than for under floor drying as the speed of tipping the grain will be limited by the speed of the grain drier. Consequently the labour and machinery requirement may be higher than for under floor drying. Continuous flow dryers use air heated to around 65-99ºC and consequently use a lot of energy. For this reason it is important to avoid over drying but reducing the temperature of the drying air will not save energy (Bomford, 1995). In terms of carbon dioxide emissions and overall energy efficiency, a direct modulating gas burner which runs on liquefied petroleum gas is the most efficient form of dryer available. The process of producing electricity is relatively inefficient and mainly uses non-renewable resources at present.

The high temperatures involved in continuous flow drying are sufficient to disinfect grain and are therefore a good idea for organic crops. They can also be used for other crops e.g. beans, peas, grass seed and maize. However, a high degree of skill is required by the operator if the grain is not to be damaged. There can also be difficulties during subsequent cooling, and if the structure of the building is infested, the pests will return to the grain anyway.

5.4.2.3. Batch drier.

As with continuous flow drying, this method has the advantage that once the grain is dry further drying in storage should be unnecessary. The grain is dried using air temperatures of 14-40ºC (FarmElectric, b). The drier is loaded and left to complete drying and cooling, each batch taking about 2-15 hours to dry depending on the load size. They can be controlled manually or automatically so the drier can be left unattended. They also have the advantage that they can be installed on either a permanent base or some types can be moved on their own wheels and be moved from one farm to another. Traditionally batch dryers were intended for small quantities of grain (2-3 t at a time) but now there are higher temperature batch dryers with capacities ranging from 38-135 tonnes of grain dried in a 24hr period (Bomford, 1995).

5.4.2.4. Low volume air extractors

These have the advantage that they are cheap and flexible in terms of usage. The simplest form consists of a circular weld mesh duct about 1m in diameter lined with hessian. A fan is attached to the top, which sucks air through the grain. Sucking air through grain needs a less powerful motor than if the air is blown. The system is usually used in round bins and is put in place as the grain is loaded. The disadvantage is that it is only suitable for feed grain as it can only dry down to about 16% MC, it is not suitable for drying down to 14% or where the grain has started off with a high MC.

Martin Lishman (company) supply a form of low volume air extractor called the ‘pile-dry pedestal’. This consists of a free-standing vertical duct. A centrifugal fan is attached to the top which can be moved from one pedestal to another. The fan can be set to suck or blow. If sufficient pedestals are used for the size of store then moisture content can be reduced by up to 2% per week. With the use of ambient air they can dry grain down to 16% and can also be used to cool the grain if night air is used. Drying below 16% moisture content is only possible when the relative humidity of the ambient air is suitable. To reliably dry grain below 16%, a heater unit is required. The system has the advantage that it can also be used for other crops such as potatoes and beans. Costs vary according to the size of store and the desired moisture content but can be in the region of £2 per tonne, or £6 per tonne for drying below 16% (Martin Lishman, 1997). However, no recommendations for using this system or information on its effectiveness could be found in FarmElectric or HGCA publications.

5.4.2.5. Dehumidifiers.

These are a relatively new idea, they have the drying capability of hot air but use ambient temperature dried air instead. These have a number of advantages:

- As the grain is not heated there are none of the problems associated with cooling the grain or condensation
- They use 3-5 times less energy than heaters,
- The size of electricity supply required is small in comparison to other systems,
- A correctly sized dehumidifier can always produce air of adequate drying potential whatever the ambient conditions,
- Moisture is not redeposited in the upper layers of the grain,
- The dehumidifier can also be used to heat or cool air so it can be used for grain drying or cooling, and can be used for vegetable/fruit chilling and storage, curing and cooling potatoes.
- They use lower air flows than conventional systems and can therefore speed up drying in systems which have become overloaded (FarmElectric, c).

The main disadvantage with these systems is their cost, a 6-8kW system suitable for a 300-500t store costs in the region of £8,000. It would take a long time for this investment to be paid pack in terms of reduced electricity cost as grain drying usually only costs in the region of £1.50-2.00/t to dry by other means. Although dehumidifiers are energy efficient in terms of the electricity they use, they can only run on electricity. In terms of energy consumption and $C0_2$ emissions most electricity sources are inefficient to produce in the first place. A dehumidifier may be worth considering where it could be used for cooling or curing other crops e.g. vegetables on the farm, but planning would be required in order to ensure that it is not required in several places at once. There is also the problem that there are very few UK suppliers (Parker Farmer, UK, being the only known supplier).

5.4.2.6. Solar grain dryers

This technology needs further development and initial capital investment is high. The main drawback with its use is that in wet seasons when the grain needs the most drying the solar power generated may not be sufficient to dry the grain. There are also problems with variability in the power supply and control of temperature when plenty of light is available, which can lead to over drying of grain.

5.4.2.7. Renewable energy sources

At present the simplest way to support renewable energy is to purchase ‘green electricity’. It is now possible to choose to buy electricity from renewable energy sources through the grid. It will probably cost up to 10% more than ordinary electricity, but it is hoped that this will not remain the case. For further information for all UK areas contact: South Midlands Renewable Energy Centre. Tel: 01908 501908.

5.4.3. Large scale storage systems

Large scale systems are worth considering for 100 tonnes or more of grain but usually they are built for 500 tonnes or more. The main alternatives for large quantities of grain are:

5.4.3.1. On-floor storage in a suitable building.

Grain can be stored loose on the floor of a suitable building. The building has to provide protection from vermin, protection from the weather, and be able to withstand the sideways thrust of the grain. It is usually possible to adapt existing on-floor stores to comply with food safety legislation. The grain can be stored to any depth provided it is dried to 14% moisture content and kept in this condition. This type of storage is suitable where:

1) Only one or two varieties of grain are grown. There is little need for segregation of grain. However, it is possible to split the store further using wooden moveable panels to enable more varieties to be stored. Air entering the different sections can be controlled by opening or closing the appropriate ducts in the ventilation system.

2) The use of the store needs to be flexible. On-floor storage is the most flexible system in that the store can be used for other purposes such as machinery storage once the grain has been moved. On-floor ducting rather than under floor venting is the most flexible system as the ducts can be removed and are less likely to be damaged than the grids required for under-floor ventilation. It is essential that the store is properly cleaned before it is used for storage again.

3) Where drying requirements are not critical. Where either no drying is required or what is needed is simple and direct.

5.4.3.2. Large scale outdoor bins/silos.

Outdoor grain bins/silos cannot be used for anything else so they do not provide the same level of flexibility as on-floor storage. Most organic cereal farmers grow several species and varieties, therefore they tend to have relatively small volumes of grain and require at least 4 bins. However, they are most likely to comply with any future changes in food safety legislation. Store loading can be slow as it is limited by the speed of conveyor and other handling systems moving the grain from trailer to bin. Thus labour and machinery requirements for grain carting may be higher than for an on-floor store.

As with on-floor storage the grain can be dried before loading into the bin using continuous flow dryers, batch dryers or dehumidifiers (see section 5.4.2) or an in-bin drying system can be used. Here the floor of the bin is perforated to allow air to be blown into the grain. The bins are fitted with fans and a dryer.

5.4.3.3. Airtight bins or silos for feed grain.

If grain is destined to be fed to livestock on the farm it can be stored without drying in airtight sealed containers. When grain is stored under airtight conditions it quickly uses up the oxygen in the container so that levels of oxygen are 1% or less. The grain is killed and most destructive organisms die or become dormant. Grain above 24% moisture content is not suitable as this may cause fermentation and taint the grain. When batches are removed from the store, care should be taken to prevent air entering, or the grain will deteriorate rapidly. Likewise only enough grain for 1-2 days feed supply should be removed at a time. Advantages of using this method are: no drying cost and a very fast rate of loading into store.

It is unlikely that this type of store would be adopted by organic farmers it is not flexible enough as it can only be used for feed grain. Most organic farmers need a system that can also store milling or brewers grain.

5.4.3.4. Costs of on-floor storage and outdoor bins/silos

For both storage methods some kind of drying and ventilation facilities are required and these costs are included in Table 34. Annual operating costs are compared in Table 35.

Table 34 Capital costs of a new grain store (500 tonnes)

	£	**per tonne**
1. Circular galvanised bins	9600	19
low volume vent fans for above	1700	3.4
Circular bins fitted with drying floor **(total)**	**61250**	**123**
2. On floor grain storage-dry grain only	35000	70
low volume vent equipment for above	2800	5.6
On floor drying with duct drying system **(total)**	**81200**	**162**
(underground ducts add £12/t)		

(Chadwick, 1996)

Economies of scale

It is important to note that the marginal cost of grain stores reduces considerably as the size of the store increases. A 1,000 tonne on-floor grain store would cost approximately £133/t and a 1500 tonne store £94/t (RASE & Thornton, 1997)

Table 35 Annual operating costs *(500 t)

	Case Study 10		Case Study 11	
Both with drying and ventilation	**Bins**	**per/t**	**On floor**	**per/t**
Depreciation (10years)	6125		8120	
Interest on capital (6%)	3675		4872	
Electricity (£1.20/ t)	600		600	
Repairs and maintenance	919		1220	
Total (£)	**11319**	**23**	**14812**	**30**

* These costs do not include interest on the value of the grain or value lost due to moisture loss.
(Chadwick, 1996)

Savings

It should be noted that the costs listed should only be taken as a guide. It is important for individual farmers to prepare or have costings prepared for their own case. Considerable savings can be made by 'do-it-yourself work' for some types of buildings using farm staff (labour costs of new buildings quoted amount to 30-40% of overall costs). In some cases savings can be made by the use of second hand materials.

5.4.4. Some small scale systems and their costs

Existing buildings can be adapted for storing, drying and ventilating grain, or relatively small bins and portable units can be used within a larger building. There are a number of storage systems on the market suitable for relatively small quantities of grain. These include:

5.4.4.1. Traditional metal silos or bins.

These are usually round bins which are cheaper than the equivalent square bins as a lighter gauge metal can be used. These have the disadvantage that they start to rust but this is not considered an important issue as they usually last over ten years.

5.4.4.2. Concrete panels

Can be used to make a storage bay within a building. When the concrete is new, a polyurethane coating can be applied to make cleaning more efficient. These systems have the advantage that the panels can be relocated and used for other purposes (e.g. animal pens) if no longer required for grain. They have the disadvantage that the grain is not covered, if the building is not vermin proof they may need to be adapted to comply with future storage standards and legislation.

If there is an existing concrete floor, a bay 2.4m high x 4.5m x 4.5m, costs in the region of £370. If additional load bearing is required due to the type of building, or the bay is to stand on its own, a bay of the same size would cost in the region of £470. (Whites Concrete Ltd, & Stone Mark)

Drying and ventilating small quantities of grain within an existing building would cost:

Capital costs (100 tonnes)

	£/tonne
Ducting and fans	10-15
Mobile drier and fan (3 HP) (capital cost £850)	1.7

(Record Sales Ltd, 1997)

5.4.4.3. Silo modules.

Consisting of a circular steel frame (or weld mesh) sited within an existing building with a strong long-life polypropylene inner lining. This system is suitable for short term storage as it does not require specialist equipment to construct. It can be put up in about 2hrs, dismantled easily to be stored in a compact form, thereby freeing the area for other uses. Grain can be dried and cooled using a pedestal and fan system supplied by the same company (Martin Lishman).

A silo with a 17 tonne capacity costs in the region of £1,175

A silo with a 43 tonne capacity costs in the region of £2,200

5.4.4.4Sacks

Some of the specialist traditional wind mills handling organic grain can only handle small quantities of grain at a time and the most convenient size of container for handling is a traditional jute sack. A 4 bushel sack requires about 3 sq. ft of storage space. If the grain is stored in a barn on the ground floor, the floor and walls need to be water proof. Alternatively the sacks can be placed on pallets or ‘duck boards’. The sacks can be stored 3 sacks high. If the sacks are to be stored on the 1st floor, the floor must be able to bear a weight of 200lb per sq. ft. Grain stored in sacks is very vulnerable to attack by rats and mice so vermin proofing measures should be incorporated into the building (Sayce, 1966).

5.4.5. Hire of storage

One possibility is to hire ‘off -farm’ storage. This is allowed by the UKROFS standards, but the grain must remain in the ownership of the organic farmer who is also responsible for the facility’s cleanliness. The grain must be completely segregated and labelled. Storage insecticides must not be used within the same building that houses organic products. These chemicals are very volatile and easily contaminate crops held in the same air space. Hiring of conventional co-operative storage costs £33/tonne (RASE & Thornton, 1997), here the farmer eventually owns an interest in the store and the grain is marketed collectively to gain a favourable price. The costs of non co-operative conventional storage are likely to be £1.10/t/month, plus £1.50/t for loading into and out of store.

5.4.6. Hire of drying equipment

Mobile cleaners and dryers are allowed by organic standards provided the organic farmer retains ownership of the grain. The organic farmer is also responsible for ensuring that the machinery is properly cleaned first. Care must also be taken to ensure that the grain does not get contaminated by combustion products of paraffin or diesel from a drier.

Farmers with large stores and co-operative stores can offer drying and cleaning facilities which may be suitable for farmers without this facility on their own farms. Currently one or two organic farmers offer this service and merchants also offer this service using their own or other farm's facilities. Other farmers hire in mobile dryers and cleaners. Costs for drying range from £2.75-9.75/tonne depending on the MC of the grain (RASE & Thornton, 1997). This compares with a cost of £1.60/t for using own continuous drier on farm. (Measures, 1997, pers. comm.)

5.4.7. Transport of organic grain

Grain is usually transported by hauliers or lorries belonging to the grain merchant. According to UKROFS standards steps should be taken to ensure that organically grown crops are not contaminated during storage or transport with non-organic crop residues or other materials. Lorries should be cleaned of all debris and inspected before loading. During transport the grain should be enclosed in such a way which prevents substitution of the crop unless the crop is travelling between two organically registered sites. The grain should be clearly labelled with the name of the product and the fact that it is organic with reference to the organic production method used e.g. 'the symbol' the name and address of either the grain producer or registered grain handler, as appropriate. This is to ensure that the person responsible for the grain can be unequivocally traced.

5.5. ECONOMIC ANALYSIS OF CEREAL STORAGE

5.5.1. The market and general demand

As with other organic produce, the increasing demand for organic grain in the UK outstrips supply and there is little danger of overproduction in the UK for the next few years (Starling, 1997b). With the tightening of standards for feed destined for organic livestock there has been a large increase in the demand for organic feed grain. To match this, the demand for feed pulses seems set to increase. It is also likely that the demand for milling wheat will continue to be strong. There is a tendency for UK organic wheat to be low in protein, as a result it is probable that the price differential between milling wheat with a reasonable protein content (minimum 10%) and feed wheat will increase. There is also little danger of the milling oat market being over supplied but the market and prices are constrained by having only one major outlet. However, it is inadvisable to grow triticale and rye without a pre-arranged outlet (Starling, 1997b). Contracts are also advisable for barley, particularly for malting barley (Lampkin, 1997, pers. comm.).

5.5.1.1. Prices of conventional cereals

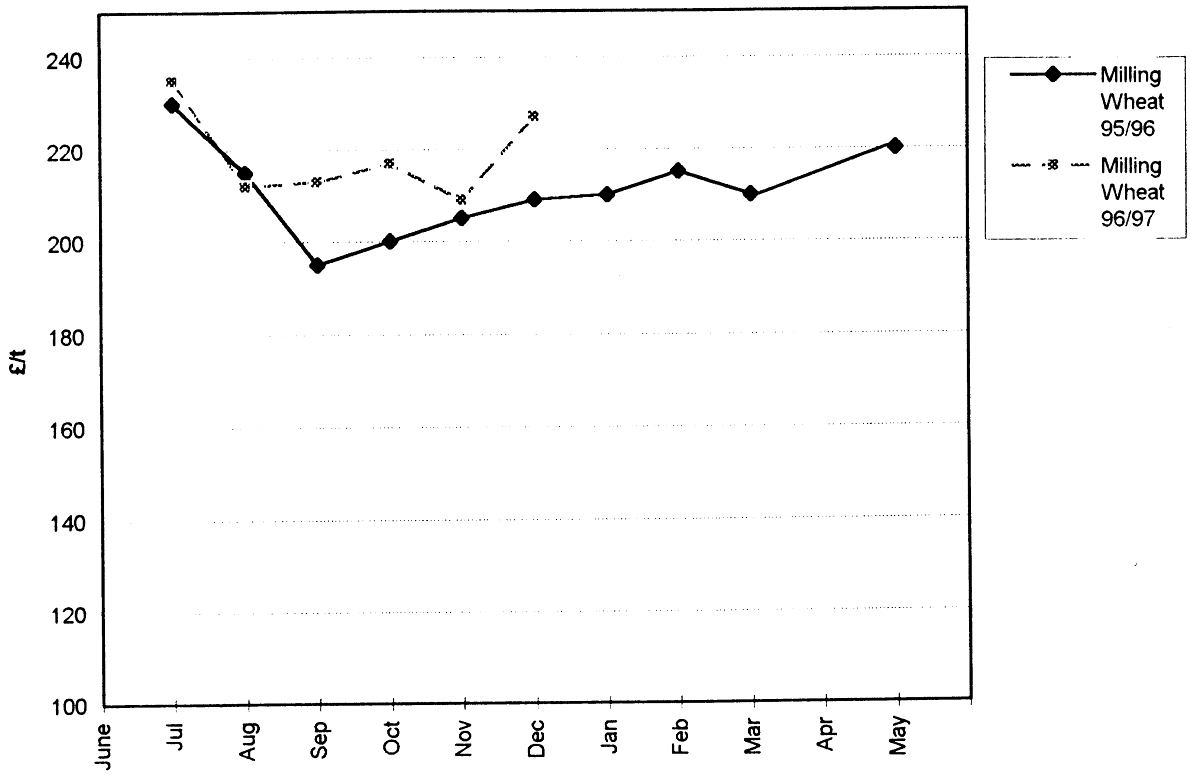
Prices are generally at their lowest at harvest time, and can be expected to rise with length of storage (normally by between £1-1.50 per month), until the next harvest approaches (Starling, 1997, pers. comm.).

5.5.1.2. Prices of organic cereals

Little published statistical information is available on organic grain prices and their fluctuation through the year, however, the prices of milling wheat, oats and rye have been collated in the 'Organic Monthly Price Survey' by the University of Wales for 1995/96 and 1996/97 (Figures 22-24). Figure 25 compares the price of organic milling wheat with those of conventional milling wheat in 1996, published in Farmers Weekly (1997).

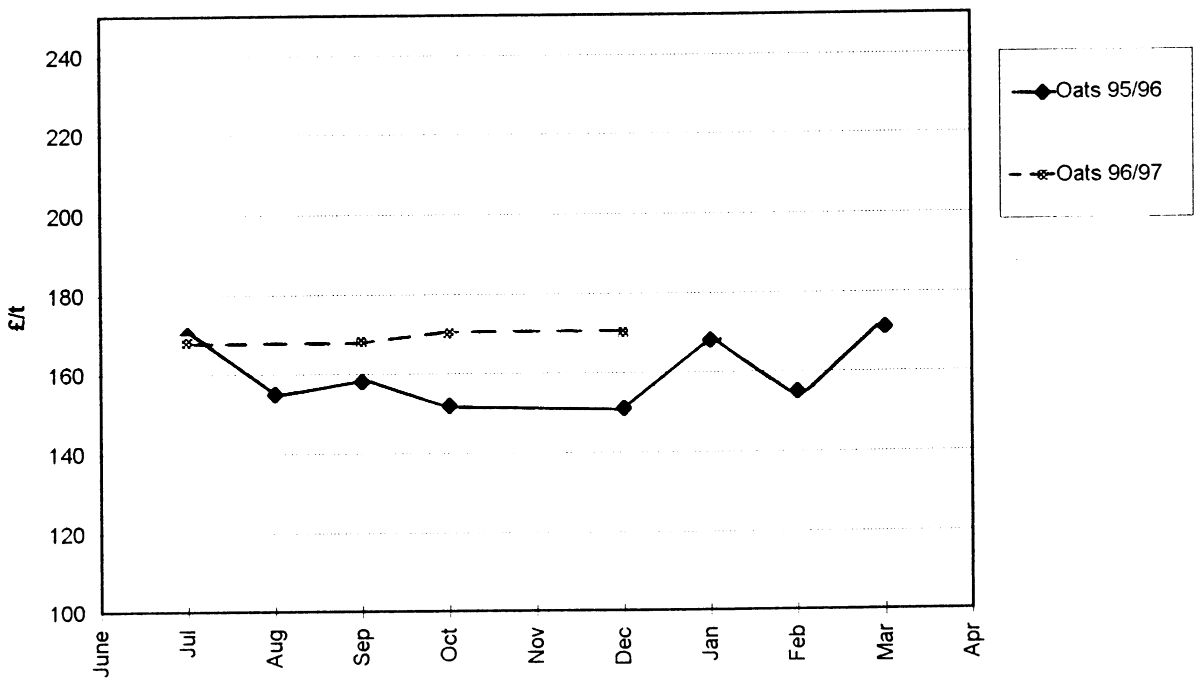
Organic cereal prices are commonly 75-100% higher and usually more stable than conventional prices (Lampkin, 1997), however, movements in conventional prices will affect organic ones, with millers expecting to pay less for organic cereals if conventional prices fall. The price of imported organic grain also influences the price of home produced cereals especially of milling and feed wheat. In general organic cereal prices follow a similar trend to that of conventional prices within the year, lower at harvest time and rising over the storage season. However, this is not always the case and sometimes the price, for example, of oats may be the same in March as it is in September (Starling, 1997, pers. comm.).

Figure 22 Organic milling wheat prices 1995-97



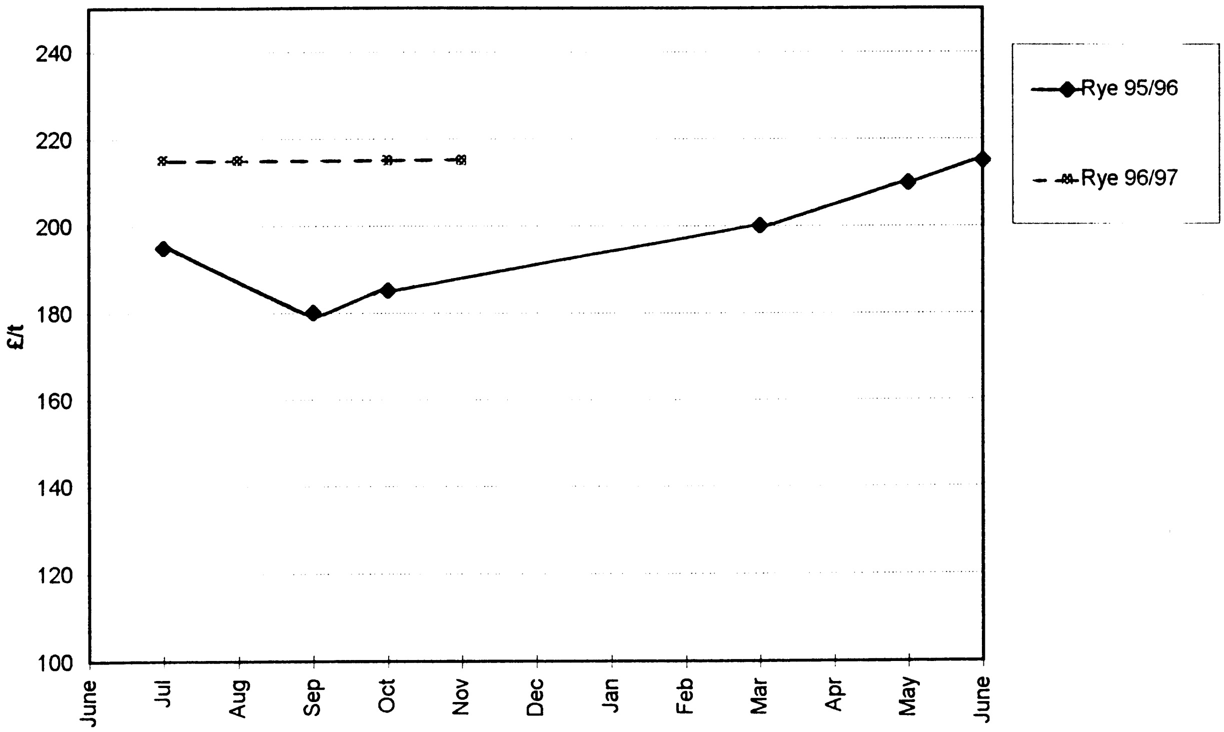
Source: Organic Price Survey, University of Wales, Aberystwth, Elm Farm Research Centre

Figure 23 Organic oat prices 1995-97



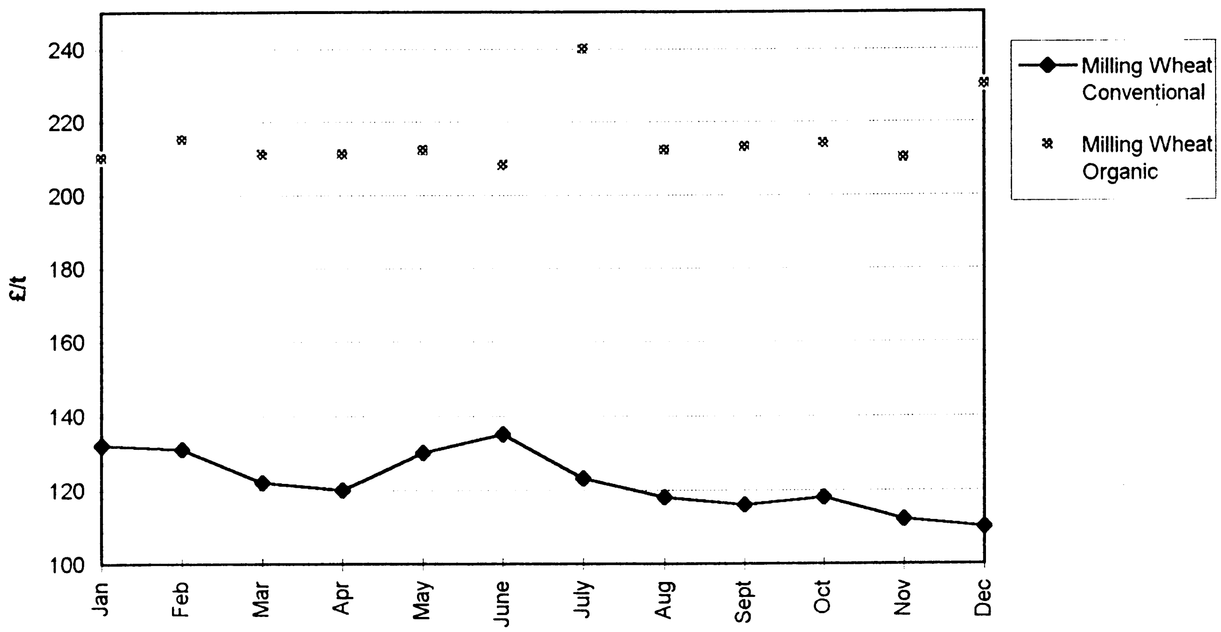
Source: Organic Price Survey, University of Wales, Aberystwth, Elm Farm Research Centre

Figure 24 Organic rye prices 1995-97



Source: Organic Price Survey, University of Wales, Aberystwth, Elm Farm Research Centre

Figure 25 Comparison of conventional and organic milling wheat prices 1996



Source: Conventional; Farmers Weekly, Organic; Monthly price survey University of Wales

Prices will also, naturally, be greatly affected by the quality of the grain, the volume being sold and the location of the farm relative to the mills. Most of the mills are situated in the south and western part of the country.

There is currently a rapid growth (40%) (Brenman, 1997) in demand for organic produce which is likely to maintain premium prices for organic cereals for the next few years.

5.5.2. The cost of storage

The costs of storage may be divided into:

- **capital (or structure) costs** for the building and equipment; this is divided over the expected life of the building, say 10 years and called depreciation.
- **interest on the capital** cost of the building, assuming this money is borrowed or loss of interest if using own capital.
- **interest on the crop** stored due to the delay in its selling time.
- **loss of weight of crop** in storage, due to drying.
- **annual running costs** of operating the store e.g. electricity or repair costs and labour.

Table 36 An example of annual cost of grain storage (500 tonnes on-floor store)

	£/tonne
Depreciation(10 years)	16
Interest (6% on initial value)[a]	9.7
Interest on wheat stored for 8 months @ 8%[b]	10.67
Loss of weight 2%[c]	2.5
Handling and drying costs, maintenance of store	2.5
Total	**41**

[a] this represents $^5/_8$ th of the average annual interest rate over the life of the asset (10% assumed). In budgeting it is the average annual interest charge over the life of the capital item that is included. A common convention is to allow half the rate of interest on the initial capital. Where the buildings or equipment have some value at the end of the depreciation period this tends to underestimate the costs, therefore an amount exceeding half the interest rate should be charged, approximately $^5/_8$ th.

[b] interest on the value of the stored crop is charged because the crop could have been sold and money used elsewhere or to reduce overdraft.

[c] a 2% moisture loss causes a reduction in weight of approximately 25 kg per tonne of grain.

(Barnard & Nix, 1979)

Table 37 Annual costs of grain storage (£/tonne)

Case studies based on 500 tonnes	10 Bin Storage	11 On-floor storage
Costs (£/t)*		
Building depreciation	12.25	16.24
Interest on capital (6%)	7.35	9.74
Electricity (ambient ventilation)	1.2	1.2
Repairs and maintenance	1.83	2.44
Total	**23**	**30**

* These figures do not include interest on the value of the grain, value lost due to moisture loss or cost of drying (see section 3.4.2)

(Chadwick, 1996)

(More details of the costs of the different systems are given in section 2.5)

5.5.3. Will storage pay?

Storage is a marketing tool which should enable a farmer to increase profits through the controlled selling of grain at the highest prices, and thus also reduces the risk involved in selling the grain at harvest time when prices are usually at their lowest.

In order to make storage pay, firstly it needs to be profitable. The additional income generated through the increase in prices over the storage season must cover the costs of storage. Secondly, storage must be financially feasible. If investing in storage it will be necessary to achieve at least a return on the capital invested which will pay the interest payments on capital borrowed and hopefully a large enough return to enable a quick repayment of the capital and provide a profit. A number of techniques are described below which can be used to assess whether investment in storage is economic, and to help assess some of the risk involved in making investments, many of them are also capital investment appraisal techniques.

Any decision making regarding whether to store or length of storage involves a certain element of risk due to uncertainty of the future. Access to past and probable future prices combined with the techniques, such as described below, can be used to aid in decision making. Due to insufficient organic cereal price information decisions on the timing of selling cereals have not been addressed here, the principles of this are dealt with in detail elsewhere, for example by Bateman (1972).

5.5.3.1. Partial budgets

These are used to estimate the additional income to be gained (and costs saved) and weigh this against the cost of any storage (and any income foregone). In some cases these budgets may show quite clearly that expenditure is or is not sensible but more generally they can always assist the farmer in weighing up the pros and cons of the situation. Total B must exceed total A for storage to be economic (see Table 38).

Table 38 Estimating a partial budget for cereal storage

Additional costs	Extra income to be gained
Capital cost of building/bins (usually spread over the anticipated life of the building) Cost of finance (interest on capital) Cost of finance from delayed sale of crop Running costs of store(electricity, repairs) Waste/ losses in store	Higher prices from; - Long term increases in price - Flexibility to sell when prices are higher
Income foregone	**Costs saved**
Reduced weight due to drying	Tax relief
Total A	**Total B**

5.5.3.2. Break-even analysis

This is an assessment of the break-even point (between profit and loss) based on average costs and expected prices. Expected prices would be based on averages of good and bad years, and would involve estimating probable future prices. In terms of storage this would involve calculating the costs of storage per tonne and from this calculating the price increase required to cover this cost.

5.5.5.5. Case study for organic milling wheat

From Table 37 derived from Section 5.4.3.4. Table 35 Case Study 10 (grain bin storage) and Case Study 11 (on-floor grain storage) it is possible to estimate that the storage charges for an 8 month period would be approximately £23/tonne (bin storage) and £30/tonne (on-floor). Therefore in order to achieve the break-even point the price of cereals would have to rise by these amounts. Examining the prices obtained for 1995/96, assuming we store from September to May.

Milling Wheat(£)	September	May	Price rise
1995/96	195	220	25

Based on this price increase, the break-even point for bin storage would just have been passed in 1995/96, if the wheat had been stored until May, but not for a shorter storage period, and not for on-floor storage.

5.5.3.4. Rate of return

This can be used to calculate the likely return on the extra capital invested in storage. It can be found be dividing the extra profit before interest by the capital invested and multiplying by 100 to arrive at a percentage figure. With regard to depreciating assets the capital is either the total initial sum required or the average capital invested during the life of the project, which takes account of the depreciating asset.

The draw back of these methods are that they it do not take full account of returns of money over a number of years or the value of these returns in present day values. More sophisticated are 'discounted cash flow' techniques. These are essentially budgets which take account of different costs and returns between years of a project, and allow flows of money in the near future to be weighed more heavily than those in the far future. This could be useful to compare different costs of large capital projects such as comparing different types of grain store. An example of how this is calculated can be found in Table 40 Appendix 1, section 5.5.5.

An alternative method, used here, is $^2/_3$ of the initial net capital as an amount midway between total initial capital and average capital requirements which gives an approximate estimate of discounted return (Barnard & Nix, 1979).

Taking the example of milling wheat in 1995/6, the profit would be

	£
Price increase(t) less cost of storage(bin) (not deducting interest)	25 16
Extra profit/tonne	9

* $^2/_3$ of the initial net capital.

If we assume the grower stored 500 tonnes of wheat the total extra profit is £4500 (500t x £9)

Rate of return = $\dfrac{4500}{*40793}$ = 11%

Rates of return should at least exceed the interest rates of borrowing money to cover costs, (8% 1995/96) and hopefully more in order to make it profitable. In this particular case it did exceed this rate but not by a significant amount. New grain storage represents a significant capital investment and can be difficult to justify in terms of return on that investment (RASE & Thornton, 1997).

5.5.3.5. Pay back

This measures the number of years needed for an investment to repay the initial capital.

From the above example of bin grain storage; it would be calculated by dividing the total initial capital cost by the additional profit created, before charging depreciation.

Initial capital £61250
Adjusted extra profit £7125 (14.25/t) costs are £10.75, depreciation not deducted

Payback would be achieved in 9 years.

Payback or repayment of capital should be planned or expected within the life of the asset, in this case within 10 years. This rate of payback is just within this period.

Table 39 Appraisal of organic cereal storage 1995/96 (Bin storage)

	Price Increase (£/t)	Break-even point (£/t)	Return on capital (%)	Payback period (years)
Milling wheat	25	23	11	9
Oats	12	23	-4	98
Rye	30	23	18	6
Averages	**22**	**23**	**8**	**38**

These figures are based on cereals prices from Organic Monthly Price Survey, University of Wales, and for storage from September to May (March for oats)

Conclusions

It is difficult to draw firm conclusions on so little statistical data. More information over at least a 5 year period would give indications of the likelihood of good, average and bad years. Based on the current figures available organic grain storage would not appear to be very profitable with low rates of return on capital invested and long payback periods. These figures are based on costs of new storage. Farmers with existing stores or with the ability to erect them cheaper are likely to have lower costs. Individual farmers do make a profit from storing organic grain if they sell at the right time. (Measures, 1997, pers comm.)

Some form of grain storage is essential since markets are unable to take all the grain at harvest time. Storage also gives the flexibility of being able to hold onto the grain if required. Farms with existing stores will continue to use these. Co-operative or hiring grain storage is likely to be an attractive option (Fengrain £33/t RASE & Thornton, 1997) compared with erecting new stores, if this is available locally. One of the large organic grain traders does store grain at its own store and on a farm for supplying millers from June-August each year.

5.5.5 Appendix 1

Table 40 Discounted Cash Flow: On floor grain store under floor drying

Storage space (tonnes) 1000								
Allowance method		**Capital cost (building)**	**Capital cost (plant)**	**Annual allowance (buildings) 4% strgt line**	**Annual allowance (plant) 25% red. bal**	**Value /sale of building**	**Tax relief @ 40%**	**Annual net cash flow**
Year								
1997	0	(39700)	(79000)				0	(118,700)
1998	1			(1588)	(19,750)		8,535	8,536
1999	2			(1588)	(14,813)		6,560	6,561
2000	3			(1588)	(11,109)		5,079	5,080
2001	4			(1588)	(8,332)		3,968	3,969
2002	5			(1588)	(6,249)		3,135	3,136
2003	6			(1588)	(4,687)		2,510	2,511
2004	7			(1588)	(3,517)		2,041	2,042
2005	8			(1588)	(2,636)		1,690	1,691
2006	9			(1588)	(1,977)		1,426	1,427
2007	10			(1588)	(1,483)		1,228	1,229
2008	11			(1588)	(1,112)		1,080	1,081
2009	12			(1588)	(834)		969	970
2010	13			(1588)	(626)		885	886
2011	14			(1588)	(469)		823	824
2012	15			(1588)	(352)		776	777
2013	16			(1588)	(264)		741	742
2014	17			(1588)	(198)		714	715
2015	18			(1588)	(148)		695	696
2016	19			(1588)	(111)		680	681
2017	20			(1588)	(84)		669	670
2018	21			(1588)			0	0
Total		**(39700)**	**(79000)**	**(31760)**	**(78749)**	**0**	**44204**	
							NVP Years 0-21 @ 10%	(90731)
							NVP per tonne	(91)

Royal Show (1997) RASE and Thornton

This shows the cost of a new grain store spread over 20 years, these values are then discounted at 10% to give their net present values. Therefore for a building costing £118,700, when discounted shows a Net present value of £90,731

5.6. POTENTIAL OF BIOLOGICAL CONTROL AGENTS, TEMPERATURE TREATMENTS ETC. FOR GRAIN STORAGE

5.6.1. Biological control agents of storage insects and mites.

5.6.1.1. Problems and legislation

In principle the use of biological control agents is acceptable in organic systems, the organisms involved occur at low levels in nature and they are commonly deliberately introduced at high levels, and used in organic horticulture, especially in protected cropping. However there are no biological control agents available for use in stored grain in the UK which is probably the primary reason why they have not been considered for use by UKROFS. In addition, there are special concerns over their use in stored products including grain. The most important being that the end users of grain may not find the principle of adding insects, mites or other organisms to grain acceptable. This is a concern also held by the end users of conventional grain.

The situation on the legality of adding biological control agents to stored grain is not clear as the 1990 Food Safety Act does not distinguish between beneficial and pest species in food products. Similarly, it is uncertain how EU food regulations would be interpreted. As far as the presence of insect and mite remains in cereal products for human consumption is concerned, it is very unlikely that these would be acceptable, they would need to be removed during the usual sieving and cleaning processes required for human consumption (HGCA, 1996).

For the use of a biological control agent to be accepted for organic use it also has to be shown that it is not injurious to human health or the environment. The mechanisms by which some biological control agents work are not fully understood and there are some concerns that bacteria for example would produce antibiotics and the exact amounts remaining in grain would be hard to quantify. However, these concerns would largely be addressed by the current Control of Pesticides Regulations (COPR) required for the registration of all pesticides used in the UK. Organisms such as bacteria, protozoa, fungi, viruses and mycoplasmas intended for use as pesticides are covered by these regulations. Data has to be supplied on efficacy and safety which can be very expensive before they can be registered with the Pesticide Safety Directorate (PSD), the cost of registration alone is around £18,000 per product (HGCA, 1996).

Insects, mites and nematode biological control agents are not subject to COPR and if they are endemic to the UK they do not even need an import licence (HGCA, 1996). Initially these would be the easiest biological control agents to be imported into the UK.

5.6.1.2. Existing products for consideration

Before the use of biological control agents would be acceptable in organic or conventional UK grain stores, more information on the cost and effectiveness under UK commercial conditions would need to be provided.

Having said this there is somewhat fragmented research and commercial use of biological control agents carried out abroad. Some of these existing products may be worth considering for certain applications.

Cheyletus eruditus**.** This is a predatory species of mite which itself feeds on mites which are pests in stored products including grain. It is used under commercial conditions in stored grain and empty grain stores in Czechoslovakia (HGCA, 1996). Since it is a mite it would be relatively easy to introduce legally into the UK but its use would have to be cleared by UKROFS for use in organic grain.

Its most useful application in organic systems would be to treat empty stores where areas are not easily accessible for cleaning. It could help ensure the store is mite free before another crop of grain is loaded. It could also be used within the grain bulk for grain destined for livestock feed. However, *C. eruditus* requires temperatures above 20ºC for good activity and there are doubts as to whether it would be effective in grain storage if grain temperature fell below 18ºC (HGCA, 1996). Since it is recommended that cereals are stored at temperatures below 10ºC for long term storage it is unlikely to be of benefit in this situation.

Costs to treat empty stores are estimated to be in the region of £2/100 sq. m. Costs for treating grain bulks are harder to estimate because they depend on the levels of pest mites, grain depth and temperature etc. but are probably in the region of £2 per 100 sq. m. of grain surface area.

The Biofac system. This product is supplied by a company in the USA and consists of a number of recommendations for pest control in stored grain and includes a staged release of a mixture of predators and parasitoids on a weekly basis. The system requires a high degree of expertise and the company marketing the product considers it essential to have expert evaluation of the pest problem and employ advisors for this purpose. The species and numbers of beneficial insects released depends upon the pests and their numbers. The system is management intensive but good results are claimed (HGCA, 1996).

There are conflicting costs published in the scientific literature and those published by the company but the figures range from 13p to 50p /tonne and £1.20/tonne.

The beneficial insects and mites used in this system are known to occur in the UK or are regularly found on imported commodities so it is unlikely that registration would be required.

The most likely application for organic grain would be in grain destined for livestock feed but it would need to be cleared by UKROFS first. As with *C. eruditus* temperature may limit its efficacy and cooled grain may not be suitable.

***Bacillus thuringiensis*.** Dipel produced by Abbott chemicals is registered in the USA for application to grain. It is applied as a dust to the grain surface or as a wettable powder diluted in water. Estimated costs are around 22p/sq.m. surface area of grain (HGCA, 1996)

This product or equivalent products would need to be registered with PSD. There is also evidence that some laboratory strains of the moths build up resistance after only a few generations of selection. This suggests that resistance could also develop in commercial use.

Since other strains of *B. thuringiensis* are allowed in organic horticulture and the toxin they produce is considered harmless to humans and most other non-target organisms it is likely to be considered by UKROFS.

5.6.1.3. Future developments in biological control

Most R&D on biological control agents is not aimed at use in stored grain and what is carried out is fragmented, but there are a number of approaches which may be useful.

- Combining different biological control agents to increase efficacy e.g. the use of parasitoids to spread pathogens amongst storage insects.
- Pheromone and food lures to attract pests to point sources of biological control agents.
- Manipulating storage conditions so that the biological control agent is favoured without its deliberate introduction (at present this research is most applicable to tropical systems)

A worrying trend in biological control agent research is the use of genetic manipulation with the aim to enhance effectiveness. Since genetically manipulated organisms are not permitted in organic systems they will not be considered by UKROFS nor any other organic standards body in any other country affiliated to IFOAM.

5.6.2. Temperature treatment of grain

Micro-organisms in flour and grain can cause economic loss and be a potential health hazard to humans and animals. In the case of wheat flour it has been shown that the number of organisms present is a reflection of the number in the grain from which it was derived which in turn is determined by storage practice. The number of micro-organisms can be reduced by cleaning and screening at the mill and good general hygiene practice (HGCA, 1992).

Storage of wheat grain at temperatures above 44ºC, preferably 50ºC for 16-24hrs has been found to give worthwhile reductions in bacterial numbers without affecting gluten quality. However, trials on how this could be achieved in the commercial situation have not been carried out yet. (HGCA, 1989). One possible way would be to dampen the grain (or take it straight from the field) heat it to the desired temperature in a screw conveyor, load it into an insulated bin and then hold it at the right temperature before cooling and milling (HGCA, 1989).

5.6.3. Controlled atmosphere storage of grain

Controlled atmosphere storage still needs to be considered by UKROFS for permitted use for organic crops. The HGCA has done research on controlled atmosphere of grains and theoretically it could be useful if ever organic grain needs to be stored for long periods of time. Long term storage of organic grain is only likely to be required if ever there is a surplus, in which case the price is likely to be low, and the cost of controlled atmosphere probably won't be justified. As with conventional grain the most likely application would be for storing malting barley for up to 6 months.

In general, pest and disease problems can be reduced to negligible levels if concentrations of oxygen are reduced to 2% and carbon dioxide levels raised to 45% within grain stores (HGCA, 1992). However, at grain temperatures below 15ºC it may take three or more weeks to control insects (HGCA, 1992).

Seed grains and those destined for malting barley need special care to avoid losses in germination and viability. Malting barley may need a period of warm storage to ensure dormancy is broken. During this time risk of pest infestation is high. The HGCA has funded research on modified or reduced oxygen atmospheres to store malting barley. The studies showed that malting barley can be stored successfully in low oxygen atmosphere for up to six months without detriment to germination or recovery from dormancy and it provides an alternative to the use of insecticides, fumigants or low temperature storage (HGCA, 1991).

5.7. RESEARCH AREAS

Research areas of most immediate benefit:

- Organically acceptable methods of store cleaning and fumigation.
- Development of energy efficient drying systems.
- Rapid testing of seed for seed borne diseases and grain entering store.
- Official collection of prices of organic cereals on an on-going basis.

Other areas of interest:

- Investigating microbial activity of organic soils and possible suppression of soil borne diseases e.g. *Fusarium* spp.
- Detection of pest insects and mites in stored cereals.
- Rapid detection of fungi, bacteria and yeasts in stored grain (HGCA currently funding some work)
- Distinguishing pest and predator species of insects and mites.
- Removal of beneficial insects and mites, and their remains from grain.
- Accurate sampling strategies for moisture content and quality (HGCA currently funding some work).

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