A D A S

Report to:	Horticultural Development Council 18 Lavant Street PETERSFIELD Hampshire GU32 3EW Tel: (0730) 263736 Fax: (0730) 265394
ADAS Contract: Manager	Jill Vaughan ADAS Huntingdon Chequers Court HUNTINGDON Cambs PE18 6LT Tel: (0480) 52161 Fax: (0480) 412049

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ENVIRONMENTAL IMPACT OF WASTE SOLUTIONS FROM HYDROPONIC SYSTEMS FOR THE PRODUCTION OF EDIBLE CROPS

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PRINCIPAL WORKERS

J Vaughan BSc, MSc Soil Scientist (author of report)

T M O'Neill, MA, PhD Plant Pathologist (co-author Section 3.2)

P Bobbin, Scientific Officer

AUTHENTICATION

I declare that this work was done under my supervision according to the procedures described herein and that this report represents a true and accurate record of the results obtained.

Jill Vaughan .... J Vaughan, BSc, MSc
Contract Manager
Date 20.4.94

Report authorised by ....
(Signature)

Date 18 April 1994

CONTENTS

Report April 1994

HDC PC 59

Environmental impact of waste solutions from hydroponic systems for the production of edible crops

J Vaughan
ADAS Horticulture
Huntingdon

Co-ordinator: J E Overvoorde

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SUMMARY

Although the health risks associated with nitrate are far from proven, the EC Drinking Water Directive requires that drinking water should contain no more than 50 mg/l NO_3. This has been followed by the Nitrate Directive which, in addition to aiming to limit nitrate contamination of drinking water, also seeks to prevent harmful concentrations of nitrate in surface waters. It is an offence to allow water from a piped drainage system underneath a nursery to enter a watercourse if that water contains a high concentration of nutrients and/or pesticides.

There are considerable capital costs and risks involved in converting to a recirculating system. The purpose of this report is to assess whether recirculation is the only method of reducing nitrate losses to levels compatible with EC Directives.

Existing and proposed legislation are reviewed followed by an assessment of the environmental impact of waste solutions on ground and surface waters. The three active ingredients (all fungicides) approved for application to the root zone of hydroponic crops (carbendazim, etridiazole and propamocarb hydrochloride) are unlikely to pose a serious pollution problem when used correctly.

Soil mineral nitrogen values after rockwool and soil-grown tomatoes and cucumbers were much greater than those found in most other agricultural and horticultural soils, exceeding 1,000 kg N/ha at some sites. There is *potential* for very large losses of nitrate-N if the soil is leached after a succession of rockwool or soil-grown crops.

The Dutch glasshouse industry is four times the area of that of the UK in a country one quarter the size of England and Wales. In addition, the glass is concentrated in only a few areas, resulting in severe surface water pollution.

Detailed studies were undertaken on seven nurseries growing tomatoes, cucumbers or peppers, covering the major areas of hydroponic production in England and three growing systems (run-to-waste rockwool, recirculated rockwool and NFT). The lowest run-off from a run-to-waste system was *c.*30% of the applied solution; water applications by some growers were 50-60% in excess of theoretical crop requirement. Lack of accuracy in irrigation is a major constraint to reducing nitrate losses. Losses from the run-to-waste systems in the survey ranged from 477 to 3,400 kg N/ha plus 138-357 kg P/ha.

Nitrate losses of this order could have a significant impact on the nitrogen content of surface waters in certain situations, especially during the summer months when inputs from other agricultural sources are small.

Using chloride fertilisers offers a good interim measure but ultimately leaching losses can only be reduced to levels compatible with the Nitrate Directive by converting to NFT or recirculating systems, or by finding acceptable uses or treatments for waste solution, such as irrigation of reedbeds, short-rotation coppice, or other crops.

The capital costs of converting to NFT or recirculating systems with sterilisation cannot be recouped by savings in water, fertilisers and other costs over a period of five years or less.

1. INTRODUCTION

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Nitrate has become a major environmental issue since 1980 when the European Community (EC) Drinking Water Directive set a standard of 50 mg/l NO_3 (11.3 mg/l NO_3 -N) for nitrate in drinking water. An increasing number of water sources exceed this concentration; the number of water *sources* which were recorded as containing nitrate concentrations above 50 mg/l at some time during the year increased from 154 in 1989 to 192 in 1990. The 94 *supplies* (water leaving treatment works) which recorded concentrations exceeding 50 mg/l during 1990 served a population of about 5.3 million. Just over half of these people received supplies derived from surface water, the rest from ground water sources (Hydes et al. 1992). Meeting the limit by blending with low nitrate water, or by chemically purifying it, can be expensive. Moreover, programmes can be undermined if nitrate levels continue to rise.

Agriculture is the main source of nitrate in drinking water (MAFF, 1993a). In December 1991, the EC Nitrate Directive was adopted by Member States. This requires them to introduce restrictions on agriculture in the catchment areas of ground and surface waters which either already exceed the 50 mg/l limit, or are at risk of so doing. Future UK and Community policy will be governed by this Directive which will be implemented from December 1995 onwards (MAFF, 1993).

In 1991, Harris produced a short review of nitrate leaching from container HONS and glasshouse horticultural systems with the emphasis on the former. The report deals only with the effects of nitrate leaching on *surface* waters. He concludes that circumstances could arise where leaching losses from HONS container units/glasshouses located close to a water abstraction point could increase summer N concentrations in a river system to rise above the EC limit for drinking water.

Growers using run-to-waste hydroponic systems can reduce nitrate emissions by reducing the percentage of feed solution running to waste, reducing the nitrate content of run-off, or a combination of both. Irrigation regimes have been investigated in HDC-funded trials (PC 23C and PC 82). Other HDC-funded trials have assessed the potential environmental benefits of using potassium chloride and calcium chloride as a partial substitute for potassium nitrate (PC 55a).

Chlorides offer considerable scope for reducing nitrate emissions but leaching losses can be minimised by converting to NFT or recirculating systems. These techniques are currently being evaluated in both HDC (PC88) and MAFF-funded projects.

One potential drawback of recirculating systems is the risk of disease spread. This can be prevented (at considerable cost) by solution disinfection. The various methods available have been reviewed by O'Neill (1992) in another HDC-funded project (CP4). The most promising methods are being compared in trials at HRI Stockbridge House (funded by MAFF, HDC and commercial companies).

Another possible solution is to pass the run-off through a biological system designed to reduce nutrient pollution such as a reedbed. This option is under trial at HRI Stockbridge House with HDC funding (PC 67).

There are considerable capital costs and risks involved in converting to a recirculating system, with or without solution disinfection. It is prudent to assess whether recirculation is the only method of reducing nitrate losses to levels compatible with existing legislation. Therefore, the objectives of the present study are:

1. To assess the environmental impact of waste solution from hydroponic systems.

2. To look at alternatives to recirculation with the aim of reducing any identified harmful effects.

2. EXISTING AND PROPOSED LEGISLATION

2. EXISTING AND PROPOSED LEGISLATION

This section outlines some of the existing and proposed legislation which could affect growers. However, expert advice should be sought before taking any action which could result in pollution or if there is any doubt about the legality of current practice.

2.1 Laws controlling pollution

Water Resources Act (WRA) 1991

Water pollution control is mainly governed by the Water Resources Act (WRA) 1991. It works in two ways:

- allows people to be prosecuted if pollution occurs.

- contains measures designed to prevent pollution happening in the first place.
  The NRA is responsible for most of this work.

Section 85 of the Water Resources Act 1991 makes it an offence to cause or knowingly to permit a discharge of poisonous, noxious or polluting matter or any solid waste matter to enter controlled waters. It is also an offence to allow matter to enter water so as to obstruct flow and aggravate pollution. "Controlled waters" means all ground water, coastal or inland waters including rivers, streams, ditches, land drains and most other passages through which water flows, and most lakes and ponds (NRA, 1992). One can "cause" pollution without acting intentionally or negligently.

A person does not, however, commit an offence under Section 85 if he/she has proper authority to make the discharge. This usually means a consent to discharge issued by the NRA under Section 88 of the Act. In practice, few farmers apply for discharge consents. The strengths of the wastes involved, the lack of dilution usually available, and the costs of treating the wastes to a form that might be acceptable to discharge, make it unlikely that an application for a discharge consent for most farm wastes would be acceptable to the NRA (NRA, *op. cit.*). Situations where wastes may be discharged to controlled waters under a discharge consent include intensive livestock units, which may be able to justify the costs of treatment plant; and where the polluting effect of the waste is relatively weak, eg with vegetable washings. It is unlikely that a discharge consent would be issued for waste rockwool solution containing 100-250 mg/l NO_3 -N, 25-40 mg/l P plus pesticides at certain times. Discharges to sewers are a possibility, but there are charges according to volume and analysis.

Consents to discharge may be reviewed; the NRA has a duty to review them from time to time. This may result from circumstances in, for example, an individual river or by the Government responding to European Directives on water quality.

Pollution offences are regarded very seriously and carry a penalty of up to £20,000 in the Magistrates Court and an unlimited fine in the Crown Court. It may also be necessary to pay for any damage caused by the pollution (eg fish killed, clean-up costs).

Section 85 of the Water Resources Act does not automatically cover all types of discharge, including discharges to land and certain lakes or ponds. However, the NRA can prohibit such discharges in particular cases by issuing so-called "relevant prohibitions" under Section 86. This power is limited to discharges "from a building or from any fixed plant". - a restrictive definition which raises complications in the case of certain farm waste disposal systems (NRA, *op. cit.*).

Section 93 and Schedule 11 contain powers to designate "Water Protection Zones". Activities likely to result in water pollution can be restricted in these areas. As at the date of this report, no such zones have been designated. The NRA is responsible for proposing designations to the Secretary of State. This would be in addition to the existing Nitrate Sensitive Areas, Nitrate Advisory Areas and Vulnerable Zones (see below).

Section 161 allows the NRA to carry out operations itself to prevent or clean up pollution and recover the costs from the person responsible (the "polluter pays" principle). Under Section 202 the NRA can ask farmers and growers for information which will assist in carrying out its job preventing water pollution.

Section 97 provides for ministers to approve Codes of Good Agricultural Practice (CoGAP). The CoGAP for water was published in July 1991. It is a practical guide to help farmers and growers avoid causing water pollution. Non-compliance with the Code does not necessarily give rise to civil or criminal liability but it could be taken into account in any legal action. Following the Code is not a defence against a charge of causing pollution. "Specialised horticulture" (and fish farming) are specifically excluded from the Code (para 2). There is no definition of what is meant by specialised horticulture; subsequent revisions of the code may include horticulture.

Codes of Good Agricultural Practice have also been issued for air (1992) and soil (1993).

EC directive on water quality for freshwater fish (78/659/EEC)

This Directive sets water quality objectives for stretches of rivers and other fresh waters. Member states are required to designate fresh waters needing protection or improvement in order to support fish life. These objectives are to be achieved through pollution controls and reduction programmes.

Food and Environmental Protection Act (FEPA) 1985, Control of Pesticide regulations 1986, and Code of Practice for the Safe Use of Pesticides on Farms and Holdings (1990)

The Regulations which have been issued under FEPA Part III set out detailed rules on the approval, supply, storage and use of pesticides. One of the basic conditions laid down for the use of pesticides is that users take all reasonable precautions to protect the environment and "in particular to avoid the pollution of water". People who use pesticides must be competent and have received proper instruction.

The Code of Practice for the Safe Use of Pesticides on Farms and Holdings (1990) gives guidance on pesticide use and precautions to be taken to prevent water pollution. In particular, the Code contains advice on possible routes for disposing dilute wastes and washings, highlighting the need to ask the NRA for advice where disposal is to land. Similar advice is also contained in the 1991 CoGAP for water. FEPA contains powers to control the levels of pesticide which may be left in any crop, food or feeding stuff.

Environmental Protection Act (EPA) 1990

The Environmental Protection Act 1990 updates the UK's pollution control systems. It brings in a system of integrated pollution control for the disposal of wastes to land, water and air.

Part I establishes integrated pollution control and gives local authorities new powers to control air pollution from a range of prescribed processes; Part II improves the rules for waste disposal; and Part III covers statutory nuisances and clean air.

2.2 Planning Law

Environmental Assessment Directive (85/337/EEC) and the Town and Country Planning (Assessment of Environmental Effects) Regulations 1988

These regulations set out the requirements for the Environmental Assessment (EA) of cert major developments for which planning permission is needed. Most agricultural projects exempt from planning control and hence from the procedures established under the Directive requiring EA of projects likely significantly to affect the environment. Cert projects may however be subject to assessment: these include, for agriculture, projects wh involve water management, poultry and pig rearing.

The EC Directive also requires assessment of projects for restructuring rural land holdings and for the use of uncultivated land or semi-natural areas for intensive agricultural purposes. However, these aspects have not been implemented by the UK (NRA, 1992). There are presently proposals before the European Commission to expand the use of EA in relation to agricultural projects (NRA, op cit).

If a farmer plans a project which requires EA, he is responsible for carrying out the assessme If a proposed project is likely to affect water quality or water resources, the NRA is interes to see that there are likely to be no adverse effects (NRA, op cit). This applies to clean surf water as well as run-off; large volumes of water are collected from glasshouse and shed ro and concrete areas during rainstorms and could overload ditches. The appropriate body m also be consulted if there are plans to build in an Environmentally Sensitive Area (ESA) National Park, on Sites of Special Scientific Interest (SSSI's) or on archaeological sites.

2.3 Control of the Use of Water

Water Act 1989
Water Resources Act 1991

Most people who need to abstract water from a "source of supply" need an abstraction licence. A source of supply can either be an inland water (eg river) or ground water. Abstractions of less than 20 cubic metres per day, which fulfil certain requirements as to location, do not need a licence. This is roughly equivalent to about 0.2-0.4 ha of rockwool crop. It is an offence to abstract water without a licence or not to comply with the terms of a licence. The NRA may impose temporary restrictions on abstraction of water for use for spray irrigation, if an exceptional shortage of rain or other emergency makes that necessary (without having to pay compensation). Such restrictions can only relate to groundwater abstractions where that is in turn likely to affect the flow of an inland (ie surface) water (NRA, op cit). At present, glasshouse growers are exempt but nursery stock growers are not.

As with pollution control, the NRA has broad powers to require information from people abstracting water, eg in relation to water flows.

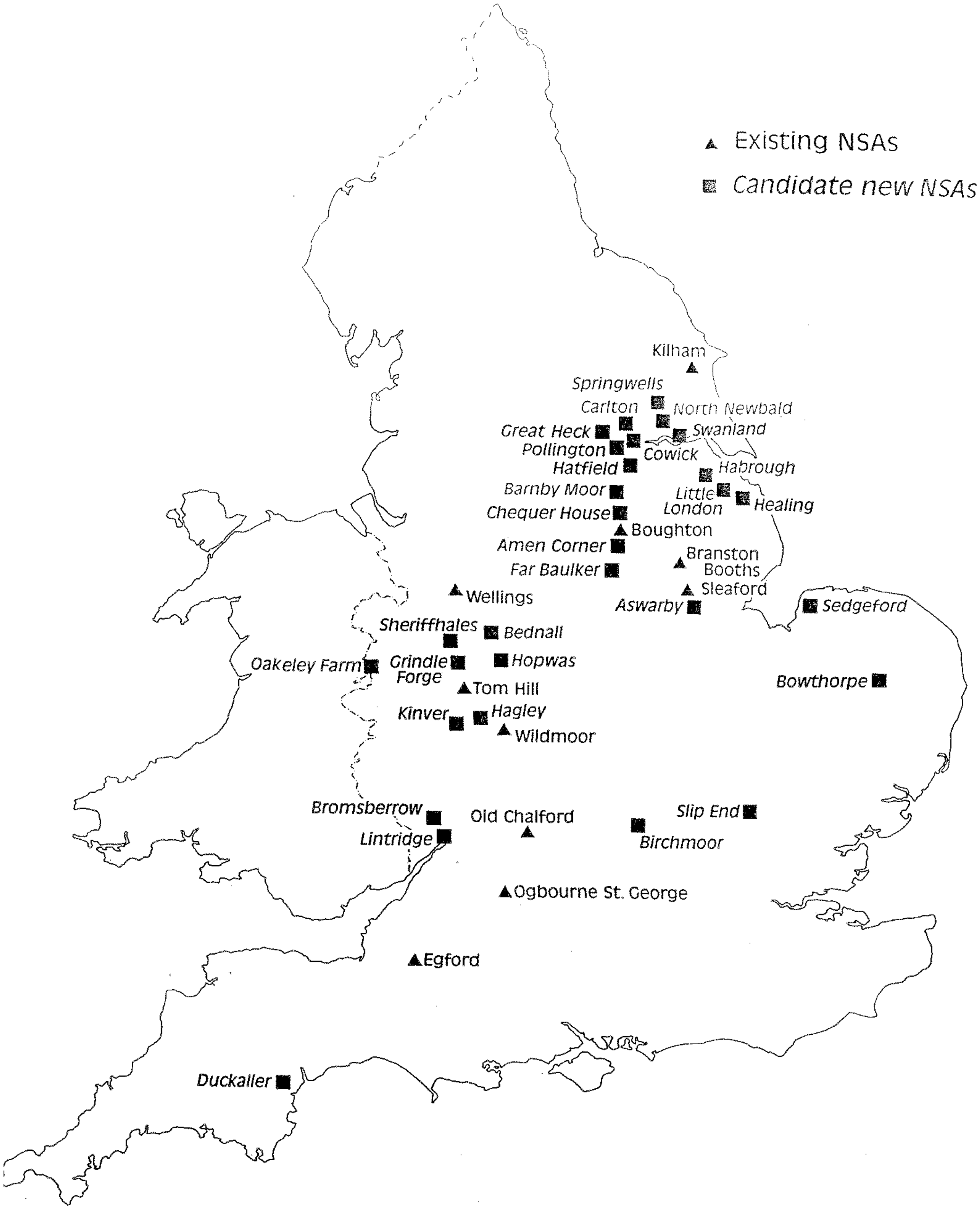
2.4 Pilot Nitrate Scheme

This was set up in 1990 to test the effectiveness in practice of measures to reduce nitrate leaching, to find out how well they could be integrated into commercial farming practice, and to gain experience in administering such a scheme on a catchment basis (Archer and Lord, 1993). The Scheme consisted of two main parts: the Nitrate Sensitive Areas (NSA) Scheme and the Nitrate Advisory Areas (NAA) Scheme. In the NSA Scheme farmers were invited to make major changes to crop management over a 5-year period in return for payments; in the NAA Scheme farmers were offered a detailed advisory visit on good agricultural practice but no payments. There were originally ten NSA's and nine NAA's; a new tranche consisting of 30 new NSA's was announced in August 1993. The locations are shown in Fig 2.1. The NSA's all have water sources with high and/or rising nitrate levels. The catchments are over sandstone, chalk or limestone groundwater sources.

The NSA's are being monitored in several ways; the concentration of nitrate in groundwater is being measured by the NRA; farmers are providing data to be fed into models to predict nitrate loss; and direct measurements of soil nitrate are being taken.

One of the requirements of the Basic Scheme, which now involves over 85% of agricultural land in the original NSA's, is a limit of 170 kg N/ha/yr as livestock manure and a closed season on spreading in autumn. This has meant the need for increased storage, at high capital investment. Only a few small glasshouse units are within the NSA's and none have so far applied to join a scheme.

Fig 2.1 Approximate locations of candidate new NSAs in England



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2.5 Laws Relating to Drinking Water Quality

Much of this legislation originates from the EC in the form of Directives. These are instructions to the UK Government, and other EC member states, to take steps in domestic law which will carry out the objectives of the Directive. Environmentally oriented directives tend to operate by setting standards (eg for drinking water quality). The Government, through the NRA, then has to meet these standards by taking whatever measures will achieve them.

EC Surface Water for Drinking Directive (75/440/EEC)
EC Sampling Surface Water for Drinking Directive (79/869/EEC)

The objective of the first of these Directives is to ensure that surface water abstracted for use as drinking water *prior to treatment* reaches certain standards and receives adequate treatment before being put into public supply; the second deals with quality measurements.

EC Drinking Water Directive (80/778/EEC)

This has been implemented under the Water Industry Act (1991) and the Water Supply (Water Quality) Regulations 1989 and amendments in 1989 and 1991. The Regulations incorporate all the standards (maximum admissible concentrations MAC's and minimum required concentrations MRC's) set out in the EC Drinking Water Directive. They also include 11 national standards. In total, numerical standards are set for 55 parameters and descriptive standards for a further two. In addition to these standards applying to water at the time of supply, a number of standards apply to water issuing from treatment works and to water held in service reservoirs within the distribution system.

Statutory responsibility for monitoring the quality of water supplies is placed upon the water companies but they are subject to checks by local authorities and by the Drinking Water Inspectorate. Monitoring information must be made publicly available.

The EC Drinking Water Directive (1980) sets standards for various substances in drinking water supplies. For nitrate there is a "guide level" of 25 mg/l NO_3 and a MAC of 50 mg/l NO_3. The EC limit refers to *nitrate*. However most growers are used to dealing in terms of nitrate-N.

To convert from a nitrate (NO_3) concentration to nitrogen (N) it is necessary to divide by 4.427. The EC limits thus become 5.6 and 11.3 mg/l, respectively. Values are quoted as nitrogen (N) throughout this report. Often the designation nitrate-N (NO_3-N) is used to distinguish from ammonium-N (NH_4-N).

The EC Drinking Water Directive also set standards for pesticides and related products in water at the time of supply of 0.1 μg/l for the total of the detected concentrations of individual substances. Pesticides are defined as fungicides, herbicides and insecticides and the related products refer to polychlorinated biphenyls and terphenyls. The Directive's standards were set at the limit of detection for organochlorine insecticides in order to minimise the occurrence of pesticides in drinking water and they were not based on toxicological evidence (Hydes *et. al.* 1992). The World Health Organisation adopts a different approach from that of the European Community. It considers the toxicology of individual substances and recommends a guideline concentration for each substance based on the assumption of lifelong consumption at that concentration.

Nitrate directive

In December 1991, the European Community Nitrate Directive was adopted by Member States; this may well have considerable impact on intensive horticulture. The Nitrate Directive aims to limit nitrate contamination of drinking water and to prevent nitrate limited eutrophication. ("Eutrophication" is the term used to describe what happens when the nutrient content of natural waters is artificially raised; there may be excessive growth of aquatic plants eg reeds and algae and periodic fluctuations in parameters such as dissolved oxygen and pH).

The Nitrate Directive includes diffuse losses of nitrate from agriculture and so excess nutrient allowed to drain into the soil would be covered. Both ground and surface waters are included; originally it was estimated that around 2 million ha, or a fifth of the agricultural land of England and Wales, might be included. Recent estimates are somewhat lower than this. The timetable for implementing the Nitrate Directive is as follows:

By June 1994	Designate as "vulnerable zones" areas of land draining directly or indirectly (a) into drinking water sources (both ground and surface water) which contain or could contain more than 50 mg/l nitrate (11.3mg/l NO_3 -N). (b) into waters which are or may become eutrophic (with nitrogen as the limiting factor).
By the end of 1995	Draw up action programmes which will specify what farmers in the vulnerable zones have to do to reduce nitrate losses.
By the end of 1999	Action programmes will be compulsory on all farms in vulnerable zones.

The action programmes will be based on "good agricultural practice" (see above), including rules on:

- The timing, rate and other conditions of fertilizer applications, both organic and inorganic.

- Closed periods for eg slurry spreading and storage capacity to be sufficient to cover the longest period during which application is forbidden.

- The overall quantity of N per ha which may be supplied by animal manure including that deposited while grazing, (normally not more than 170 kg N/ha with a higher limit of 210 kg N/ha for the first four years after the measures come into effect).

3. ENVIRONMENTAL IMPACT OF WASTE SOLUTION ON GROUND AND SURFACE WATER

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3.1 Nitrate and Phosphate

Nitrate is extremely soluble: 1 kg calcium nitrate will dissolve in 1 litre (ie 1 kg) of water. Nitrate is found in most natural waters, both surface and underground. Concentrations in these waters have been increasing steadily for the past 30 years. At the same time, quantities of nitrate fertilizer applied to crops have also been increasing. The two trends are well correlated but this does not imply a cause and effect relationship. The rise in nitrate concentration in aquifers and drinking water has increased in line with population and as farming has intensified to feed the increased numbers of people (Addiscott et al, 1991).

After the last war, food production had to be increased. The British Government introduced a subsidy on the use of fertilizers that lasted until 1966. There was also a significant national change from pasture and rough grazing to arable cropping during the period 1939 to 1946, mostly in the South of England and East Anglia, and there has been no substantial reversion to grassland since that time. Evidence for nitrate release from ploughing old grassland has been reviewed by Young (1986). He concluded that this practice releases between 200 and 400 kg N/ha for leaching to groundwater. Addiscott et al (op cit) estimate up to 4 t/ha may be released over 20 years.

There are two main pathways by which nitrate leaves the soil. Firstly it may travel in solution to an underdrainage system and thence to an outfall. It may then affect surface waters such as dykes or rivers, depending on the position of the outfall. Secondly, nitrate may percolate down through the soil towards the water table.

The way nitrate moves through a soil depends on several soil properties.

Water normally moves much more freely through sandy or gravelly soils than through clay soils, unless there are large cracks. Silt soils are intermediate but they have the capacity to hold much more water than sandy soils. Organic and peaty soils are very moisture-retentive. The more water a soil can hold, the more has to be displaced for losses of nitrate to occur, so the capacity of the soil to hold water is important for slowing down nitrate loss.

Soil is made up of about 50% by volume solid particles, the rest is air and water. Water can normally percolate easily down through soil. The speed at which it moves depends on factors such as the soil particle sizes and the degree of cracking. Channels in soil are known as `pores`. The flow of water in a pore of 1mm diameter is 10,000 times greater than that in a 0.1mm pore. If there are very large and continuous pores or cracks water flows rapidly down through the soil without any appreciable interaction with water and nitrate held within soil aggregates.

Soils with only slowly permeable subsoils usually have underdrainage systems. Water moves laterally on top of any impermeable layer as well as into and through the drains. Drainflow can be collected, measured and analysed, but this ignores any lateral flow.

Nitrate has become a problem for farmers and growers as a result of the EC Drinking Water Directive and the Nitrate Directive (for details see Section 2). This legislation came about because of the human health risks and environmental problems associated with nitrate. These are outlined briefly below.

3.11 Health Risks Associated with Nitrate

Nitrate itself is not toxic; it only becomes a potential hazard when it is converted into *nitrite.*

Two health problems have been linked with nitrite in the diet:

blue-baby syndrome or methaemoglobinaemia
stomach cancer.

The last death due to blue-baby syndrome in the UK was in 1950 and the last confirmed non-fatal case in 1972. Addiscott *et. al.* (op cit) reviewed the available literature and found no cases of blue-baby syndrome associated with tap water from the mains supply. The majority of cases have occurred when the water contained in excess of 22 mg/l N and was often contaminated with bacteria as well.

Stomach cancer has also been linked with the concentration of nitrate in drinking water. The mechanism suggested is that nitrite produced from nitrate could react in the stomach with an organic compound coming from the breakdown of meat to form an N-nitroso compound. These compounds can cause cancer (US National Research Council, 1981).

However, while nitrate concentrations in water have been increasing during the past 30 years the incidence of stomach cancer has been declining (Addiscott *et. al.* op cit). A substantial proportion of the nitrate we consume, often at least half, comes from food rather than water. Although leafy vegetables such as lettuce and spinach contain nitrate, they also contain Vitamin C, which is reputed to be an anti-cancer agent. A lower incidence of cancer has been associated with a high daily intake of green/yellow vegetables by Hirayama (1982).

The evidence to link stomach cancer with nitrate in water is very limited although there may be a time-lag between exposure to nitrate and diagnosis of cancer. Blue-baby syndrome is also clearly not a current problem in the UK. Nevertheless the standards set by the EC are now in force and we have to learn to live with them.

3.12 Environmental Effects of Nitrate and Phosphate

Eutrophication can be defined as nutrient enrichment typically leading to increased algal growth and periodic wide fluctuations in parameters such as dissolved oxygen and pH. In fresh waters, phosphate is the principal limiting nutrient whereas in estuarine and coastal waters it is nitrate (NRA, 1992). The long-term subtle effects of eutrophication in watercourses are poorly documented, although it is likely that habitats and animal communities will be significantly altered (NRA, op cit). Surplus nitrogen causes many aquatic plants such as reeds to take their nitrate from the water rather than the bank and thus put down feeble root systems that are not strong enough to anchor the plant when water flow increases. River banks may become eroded as the reeds are washed away, loosening the soil and probably bringing more nitrate (and phosphate) into water from the organic matter in the eroded soil. Alternatively, reeds may grow to excess thus narrowing waterways and possibly overloading and damaging banks. Water supply conduits become clogged and machinery damaged.

Estuaries are categorised into four quality classes ranging from "good" (Class A) to "bad" (Class D) based on the biological, aesthetic and chemical quality of the water (DoE, 1993). Between 1958 and 1980 there was a steady improvement in the quality of estuaries in England and Wales. Since 1980 there has been a gradual deterioration, mainly explained by three factors in roughly equal proportions: changes in survey methodology, the effect of two hot, dry summers and discharges from sewage works, industry and farms (DoE, op cit).

Coastal waters are also covered by the Nitrate Directive (see Section 2). Waste products and effluents containing contaminants reach the marine environment, principally from rivers and from direct pipeline discharges. (The UK will cease the disposal of sewage sludge at sea by the end of 1998). Nitrate discharged into the sea can cause excess growth of marine algae.

Phosphate is most often the limiting nutrient for algal growth in fresh water ecosystems (NRA, op cit). Much of the "load" present in rivers and lakes comes from treated sewage, but agricultural inputs may be significant. Fish cage-rearing adds large amounts of phosphate and can be locally very polluting. Another important source of phosphates is pig slurry.

Increasing and high levels of phosphates often result in algal blooms, especially in still waters such as lakes and reservoirs. The limiting concentration is about 10µg/l (1 µ = 0.001 mg). Algal blooms are unsightly and if water from contaminated lakes is required for drinking it has to be given expensive treatment to remove the algae. Large variations in dissolved oxygen and pH caused by algae photosynthesising during the day and respiring at night have been known to kill fish. Toxins may be produced by blue-green algae. These have caused illnesses in people using reservoirs for recreation and severe illness and death to animals. Phosphorus in lake and river sediments can be remobilised and recycled causing increased algal growth after the pollution has ceased.

3.13 Nitrate Trends in Rivers

In 1986, the DoE's Nitrate Co-ordination Group reviewed long term data from 25 rivers and shorter term data from 149 sites. It concluded that nitrate concentrations had increased at varying rates, being generally higher in central and south eastern areas, although there were indications that trends were levelling off from the mid-1970's (NRA, op cit). Crude assessments of annual rates of increase are shown in Table 3.131.

Table 1.131 Geographical variations in the rates of increase of nitrate concentration rivers

Area	Increase in nitrate concentration mg/l per year
Scotland, Wales, North West	0.1-0.4
North East	0.1-0.7
Yorkshire, Severn Trent, Thames, Southern, Wessex	0.3-0.8
Anglian	0.7-1.1

(After NRA, 1992)

Many rivers exhibit winter peaks of nitrate, which are probably associated with surface run-off from the land and not from sewage effluents, which would be diluted in high river flows. The implication is that rising nitrate levels in the monitored rivers are due to agricultural practices; rivers exhibiting positive trends are not restricted to principally arable areas.

The mean quarterly nitrate concentration at Walton on the River Thames has increased from about 2.5 mg/l N in 1929 to over 7.0 mg/l in 1979. Modelling has been used to explain the observed trend (Onstand & Blake, 1980). Data on land use, inorganic fertilizer use, animal production and crop yields were used to generate estimates of the amount of nitrate available on the land over the period 1922 to 1975. Despite some gross assumptions, this accounted for 78% of the observed variance. The effects of a number of plausible options in agricultural trends were also assessed to the year 2000 and river nitrate levels were expected to rise still further.

River and canal water quality has been monitored in a series of national surveys (DoE 1993). Rivers and canals are classed as `Good` (1A and 1B), `Fair` (2), `Poor` (3) and `Bad` (4). About 15% of the total river length in England and Wales was downgraded and about 11% upgraded in 1990 compared with 1985. Overall the estimated net downgrading of river length in England and Wales since 1985 (about 4%) is mostly explained by the same three factors that affected estuary quality: improved monitoring; the effect of two hot, dry summers in 1989 and 1990 and increased discharges from sewage works, industry and farms. It is estimated that the contribution of each of these factors to the overall net deterioration in river water quality was about the same (DoE op cit).

Substantial amounts of data are also collected regularly on a considerable suite of parameters at river locations all over Great Britain. These include BOD (Biological Oxygen Demand), phosphate, nitrate, zinc and certain pesticides. This is part of the Harmonised Monitoring Scheme (HMS), which covers 230 sampling points in Great Britain. Most of these sites are situated at tidal limits of major rivers or points of confluence of significant tributaries. Some of this data is summarised in Table 3.132

Table 3.132 River water quality: distribution of annual mean concentrations of selected parameters across monitoring sites (whole of Great Britain)

	Average % distribution over 5-year periods		
	1977-81	**1982-86**	**1987-91**
Nitrate mg/l N Over 4.0	36	36	37
Over 1.6 up to 4.0	34	33	30
1.6 or below	30	31	33
Orthophosphate mg/l P Over 0.36	32	34	37
Over 0.06 up to 0.36	35	34	29
0.06 or below	33	32	34

(after DoE, 1993)

3.14 Causes of Rising Nitrate Trends in Rivers

Water may become polluted by discharges, run-off, leaching from soil, acid deposition or because of pollution incidents.

One important and perhaps surprising piece of information is that all the land in the UK, whether in agricultural production or not, receives up to 40 kg N/ha each year from the atmosphere, in rain, aerosols and dust. This amount is about one fifth of the average annual application of nitrogen fertilizer to arable crops. If this amount dissolved as nitrate in the average amount of water draining from arable land in East Anglia it would give a concentration exceeding the EC limit of 11.3 mg/l NO_3-N! (Addiscott *et. al.* op cit).

At the end of 1991, there were about 107,000 discharge consents (see Section 2) for England and Wales ranging in size and effect from major industrial and sewage effluent discharges to minor surface water outlets (DoE, op cit). About 8% of these consents related to sewage treatment works. Some of these works were in breach of their discharge consent conditions; the proportion of sewage treatment works in breech of consent ranged from 1% for Northumbria to 27% for South West, with an average of 7% for England and Wales as a whole.

In 1991 there were 22,469 water pollution incidents in England and Wales which were substantiated by the NRA. This compares with 12,600 reported incidents in 1981. Increases in the number of reported incidents in recent years may partly reflect heightened public concern about pollution and specific encouragement by the NRA to get the public to report incidents. Table 3.141 shows the causes of substantiated pollution incidents reported in 1991.

Table 3.141 Substantiated water pollution incidents in England and Wales for 1991 by cause

	%
Farm	13
Industrial	12.5
Oil	23.5
Sewage/water	28
Other	23

(after DoE, 1993)

The number of major water pollution incidents caused by farming went down from 239 in 1990 to 99 in 1991, but the number of prosecutions increased from 123 to 159, respectively. The large reduction in reported major farm pollution incidents may have been partly as a result of the 1991 Silage and Slurry Regulations, which require farmers to have adequate storage facilities to prevent pollution. The drier than usual weather may also have been a contributory factor. Great damage can be caused by silage effluent which is up to 200 times as polluting as untreated sewage and cattle slurry which is 100 times as strong.

Harris (1991) attempted to estimate the effect of discharges from HONS container units on nitrate levels in surface water. The importance of point source inputs of waters with high nitrate concentration will depend on many factors which include the quantity of water being discharged, the background N level and the volume of water in the surface waters. High point source inputs will particularly cause a problem when river discharges are low and the point of entry of the pollution is close to an abstraction point (Harris, op cit).

Effective rainfall is highest in the winter months, with sub-surface drainage contributing to catchment run-off typically between December and March. As a result, catchment flows tend to be highest between November and May with particularly low baseflows often in the period late June through to early September (Harris, op cit).

Muscutt et al (1991), found that nitrate leaching was highest in the UK in late autumn-early winter following a flush of nitrate from the soil. During winter N concentrations fell, before rising again through the spring following inorganic fertiliser applications. Nitrate leaching in the summer was usually very low. However, under drought conditions, very low river flows provide little opportunity for dilution of point source inputs such as the recognised high nutrient discharges from sewage treatment plant outfalls. Under the extreme conditions experienced in 1976, it is well known that problems were experienced with summer nitrate concentrations in many southern England rivers (Harris, op cit).

Harris describes the "worst case scenario" as follows:-

- Summer discharges resulting from overhead irrigation to HONS container beds or from similar circumstances in glasshouses.

- A catchment with above average area of HONS containers or glasshouses.

- A catchment with low baseflows either due to established intensive under-drainage (causing lower watertables and potentially less groundwater/spring inputs) or due to periodic drought conditions.

- Background river N concentrations already near to the EC limit - more likely under drought conditions.

Under dry conditions, experienced in many parts of the UK during recent summers, surface run-off has been almost exclusively confined to "paved" areas. As a result the opportunities for dilution of high N water from horticultural holdings will depend upon the catchment and the proximity of an urban area upstream of the potable water intake. As high N leaching has been related to intensive agricultural production, and in the summer months, drainflow is likely to cease, horticultural discharge may become the dominant N source in many surface waters (Harris, op cit).

3.15 Nitrate in groundwaters

Water supplies stored in porous rocks (aquifers) are used and replenished over long time scales and much of the nitrate from changed farming practices has not yet reached underground water. This has been described as a "nitrate time-bomb".

In some areas where soil overlies chalk, water remains in aquifers for a long time (50 years or more) while, for example, in fissured limestone or sandstone the residence time is much less, perhaps five years or so. This means that any changes in agricultural practice will not necessarily make any difference to nitrate concentrations in bore hole water for many years to come. By boring into the aquifer rock and measuring nitrate in the water, hydrogeologists found that most water moves downwards through chalk at a rate somewhere between 0.5 and 1.5m in a year with a small proportion moving much faster (Addiscott *et. al.* op cit). The proportion moving faster through fissured limestone is much greater. The response time can be a few years or, in extreme cases, one season.

Long term data exist for many public supply boreholes, but these are imperfect indicators of trends in aquifer quality (NRA, op cit). Water from boreholes consists of a mixture from different depths and its quality is influenced by borehole construction, flow and pumping regime. Data from research boreholes are more reliable but are available for relatively short intervals. Of those sources with reliable data, some show little increase in nitrate since 1970, and a few have shown a decrease, but some display an overall rising trend. Analysis of pore water from the unsaturated zone can indicate whether nitrate levels will continue to rise, although predictions are difficult as there is a risk of recharge short-circuiting the unsaturated zone during wet weather.

Nitrate migration in ground water appears to be highly variable; it is non-systematic in Norfolk Chalk, where there is also evidence of dispersion. In contrast, in the Isle of Thanet Chalk, downward migration is steady but slow and there is no evidence of lateral dispersion. Vertical stratification in the saturated zone is probably due to the aquifers not having reached an equilibrium with the "recharge" water's quality. In many cases, this is likely to take decades, or perhaps centuries (NRA, op cit).

A study on the Isle of Thanet, carried out by Southern Water (1985), indicates that nitrate is moving vertically downwards at a rate of about 0.5 m/year. As the chalk is largely sterile, it is unlikely that biological processes will significantly reduce the nitrate content; its arrival at the saturated zone is thus irreversible and unavoidable. Concentrations of nitrate in the ground water are about 30 mg/l beneath fertilised arable land, about 10 mg/l beneath fertilised permanent grass and less than 3 mg/l beneath unfertilised permanent grass, although single ploughing events can cause peaks in excess of 50 mg/l. Trend analysis of the Thanet sources shows no clear upward or downward behaviour in the last thirty years. Nevertheless, future increases are expected as the effects of post-war ploughing and fertiliser usage eventually reach the saturated zone.

For some catchments what will happen in the future can only be predicted by using a mathematical model using leaching rates estimated for different crops. For example, the catchment above the Hatton ground water source in the Severn Trent Region occupies about 3,000 ha (Oakes, 1989). In almost half, dairying is the main agricultural enterprise, a quarter is used for arable production and there is a significant area of forestry. The ground water there exhibits a rising trend in nitrate concentration. (Fig 3.15). The model predicts exceedance of the EC Drinking Water Standard early in the next century. It has been concluded that the necessary reduction in nitrate leaching cannot be achieved merely by improvements in the management of present land use, but that restrictions on land use are required which must involve a reduction in the intensity and area of arable cropping, and an extension of sympathetic grassland management practices.

There is evidence that ground water nitrate concentrations can be reduced by the control of farming practices. Several years ago, increasing nitrate trends at Batheaston and Monkswood Reservoirs in the Wessex Region were causing concern, with predictions indicating exceedance of the EC limit within 20 years (Tuckwell and Knight, 1988). Financial analysis indicated that, in this case, control of agricultural activities was the cheapest option. Between 1985 and 1987, 73% of Batheaston and 43% of the

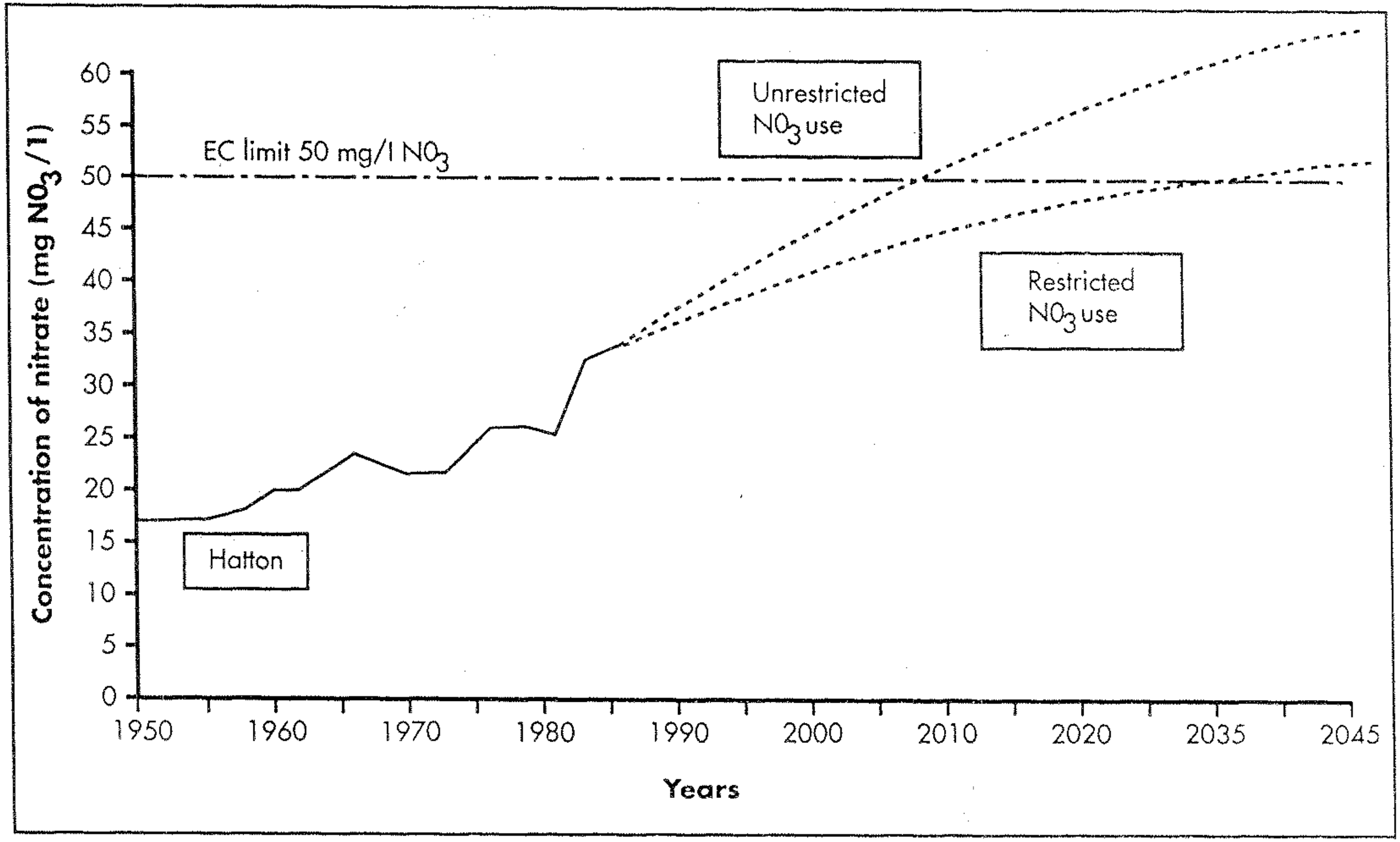

Fig 3.15 Historic and future predictions for nitrate in groundwater in the Hatton Catchment (after Oakes, 1989 in NRA, 1992)

Financial analysis indicated that, in this case, control of agricultural activities was the cheapest option. Between 1985 and 1987, 73% of Batheaston and 43% of the Monkswood Catchments were therefore subjected to restrictive agreements: the main change was from cereal production to permanent grassland for sheep. Since then the winter maxima of nitrate concentrations in Batheaston have stabilized and nitrate concentrations in springs feeding the reservoir are decreasing.

3.16 De-nitrification

Microbes in the soil not only produce nitrate from organic matter, they can also change it to nitrogen gases. This process is known as de-nitrification. It occurs only if the microbes are starved of oxygen i.e. it is an anaerobic process. Nitrogen gas, N_2 or nitrous oxide, N_20 is produced.

Soil usually becomes anaerobic simply because it is wet. Oxygen diffuses about 10,000 times more slowly through water than through air. Wetness is not the only factor involved; the microbes demand for oxygen develops because there is organic material available which they can decompose. Denitrification tends to be patchy, occurring in "hot spots" and this makes it extremely difficult to measure, especially in field experiments. The *potential* for de-nitrification to occur in soils is very great: waterlogged soils kept warm in the laboratory (at 25°C say) and supplied with plenty of easily-decomposable organic matter will rapidly use up the supply of oxygen and the resulting de-nitrification may destroy nitrate at a rate equivalent to 30 kg/ha/day (Addiscott et al, op cit). Rates of de-nitrification in soils in the field (ie outside) are more likely to be of the order of 3 kg N/ha/day.

Areas of soil in greenhouses under the plastic floor covering are almost certainly waterlogged and anaerobic. If there is also a source of organic matter then de-nitrification could occur. Whether this is a desirable process depends on the gas formed. Nitrogen gas, N_2, is no problem because it makes up 78% of the atmosphere, but nitrous oxide (N_20) is implicated in global warming, and the depletion of the ozone layer. The ratio of N_20:N_2 in the gases formed during de-nitrification depends on a combination of soil factors and is difficult to predict with certainty. In general non-acid soils in the temperate regions emit mainly nitrogen gas, except when there is a large concentration of nitrate in the soil. On a global scale the amount of nitrous oxide emitted from soils is twice the amount produced by burning fossil fuels and four times the amount evolved from the oceans (Jenkinson, 1990).

3.17 Water supply and use

Abstraction of water from aquifers has increased greatly during the last few years, particularly in the populous south-east England overlying chalk (Addiscott et al, op cit). Water abstraction has increased to such an extent that the water level in these aquifers is sinking and some springs have ceased to flow. This means that there is less scope for water containing too much nitrate to mix with older water containing less.

The main uses of water are shown in Table 3.17. Although the electricity supply industry is the highest overall user, public water supply was the main purpose for abstractions in all but the Welsh and Severn Trent Water Regions, where the electricity companies were the main abstractors.

Table 3.17 Estimated actual abstractions from all sources by purpose in 1991 (after DoE, 1993)

	Million litres per day
Electricity supply industry	30,361
Public Water Supply	17,563
Other industry	5,472
Fish farming, cress growing, amenity ponds	3,883
Spray irrigation	365
Mineral washing	172
Agriculture (excluding spray irrigation)	134
Other*	1,254

*Other includes private domestic water supply wells and boreholes, public water supply transfer licences and frost protection use.

There has been a decline in water use by industry due to increased efficiency, recycling and the contraction of the industrial base of the major water-using industries.

The rate of water abstracted for spray irrigation increased from 298 m litres/day in 1989 to 378 in 1990 and 365 in 1991. This was largely as a result of the hot, dry summers in 1990 and 1991. Although relatively small in total, abstractions for spray irrigation may have a significant impact on available resources. Such abstractions are highest in periods when water resources may be already stretched, and almost all the water used in this way is lost to the atmosphere or ground (DoE, op cit). In contrast, abstractions for the electricity supply industry are very high, but most of the water abstracted is returned to rivers close to its sources and can be used again.

Drought orders have been issued in 10 of the 17 years since 1975, being most frequent in the South West Region until 1990 when a major new reservoir was completed. The prolonged drought through 1990 and 1991 mainly affected eastern and southern England where ground water resources were depleted by low recharge during a succession of dry winters.

3.18 Drinking Water Quality

Water supply companies in Great Britain are responsible for assessing the quality of the water they supply through regular sampling of discrete "water supply zones" in which not more than 50,000 people reside. In England and Wales, the Drinking Water Inspectorate audits water companies to check whether they comply with the regulatory requirements. Local authorities may also check the quality of water supplies within their areas.

In England and Wales, over 2.6 million determinations for individual parameters in samples were taken in from the 2,577 supply zones in 1991. There were 41,430 determinations for nitrate; 2.8% of these exceeded the 11.3 mg/l NO_3-N standard and 94 water supply zones (4%) did not comply with the standard (DoE, op cit).

Water companies have entered into legally binding undertakings to take specified steps to secure or facilitate compliance with the 11.3 mg/l NO_3-N standard by 1995 or earlier. In most cases the steps involve blending with low-nitrate supplies or installation of de-nitrification treatment processes. (The first full scale ion exchange de-nitrification plants were commissioned by Anglian Water Services Ltd and South Staffordshire Water PLC during 1990). There was an increase in the number of groundwater sources that exceeded 11.30 mg/l NO_3-N in 1990 compared to 1989, mainly in the Severn Trent and

Thames areas. There was also an increase for surface waters mainly in the Anglian and Severn Trent areas (Hydes et. al. 1992).

The water companies concerned attributed the increased number of affected water sources to the exceptional weather during 1990 which caused peaks of nitrate. For example, it is possible that the dry weather caused greater fissuring of the ground thus allowing increased movement of nitrate-rich water into some aquifers and that heavy rain following prolonged dry periods caused peaks of nitrate rich run-off into some surface water sources.

3.21 Pesticides applied to the root zone and their fate

There are approximately 450 individual substances approved for use as pesticides, of which about 360 are registered for agricultural use in the UK; only three active ingredients are approved for application to the root zone of hydroponic crops: carbendazim, etridiazole and propamocarb hydrochloride.

In a hydroponic system under glass there is no surface run-off. In conventional rockwool systems pesticides are applied to the root zone via the drip irrigation system and remain in the slab for an unknown period until they break down or are displaced by incoming solution. The waste solution containing residual pesticide leaves the rockwool slab via the slits in the plastic wrapper and then runs between the polythene sheets and into the soil.

Between double rows the soil beneath the polythene is moist or even saturated from waste solution. However, the soil under the paths may be very dry and in certain types of clay soils large cracks may develop. Waste solution finding its way into cracks may flow quickly with very little opportunity for absorption of the pesticide on soil clay and organic matter (Rose et al., 1991). An effective pipe or plastic underdrainage system also increases the risk of pesticide pollution, especially if the outfall is directly into a ditch or stream.

Prophylactic treatments primarily of propamocarb hydrochloride, are normally applied at and/or shortly after planting between November and February. This coincides with the period when rainfall is usually higher than in the summer months and the water level in dykes and rivers is also at a maximum. Pesticide pollution during the summer months may have a greater environmental impact due to the smaller volume of water available to dilute the active ingredient.

Table 3.2.1 lists the pesticide products approved for application to the root zone of hydroponic crops. The concentration of active ingredient (a.i.) at the recommended application rate is *c*.20 mg/l for carbendazim and etridiazole but only *c*.0.2 mg/l for propamocarb hydrochloride. The a.i. is diluted in the case of rockwool crops by the volume of solution within the slab at the time of application. This varies from abc litres per plant for tomatoes to about 9 litres per

Table 3.21

Pesticides approved for application to the root zone of hydroponic crops

Product	Chemical	Active Ingredient content	Crop(s)	Harvest interval	Application interval	Max no of applications/ year	Dilution	mg a.i per litre applied solution	Vol/plant (litres)	Off-label approval	Expiry date
Filex	Propamocarb hydrochloride	722 g/l	tomato cucumber	2 days	-	Tomato 4 Cucumber 8*	2.5 ml/10 l dil feed	0.18	0.5	91/0828	31.12.96
Derosal WDG	Carbendazim (MBC)	80% w/w	NFT tomato	zero	14 days	No max specified	25 g/ 1000 l solution	20.0	-	Label recommendation	-
Aaterra WP	Etridiazole	35% w/w	NFT tomato	3 days	6 weeks	No max specified	60 g/ 1000 l solution	21.0	Not specified	Label recommendation	-
Aaterra WP	Etridiazole	35% w/w	rockwool tomato	24 hours	Not specified	No max specified	60 g/ 1000 l solution	21.0	Not specified	0795/91	31.12.95
Bavistin FL	Carbendazim (MBC)	500 g/l	hydroponic cucumber	2 days	Not specified	16*	4 ml/100 l	20.0	0.5	0713/92	30.6.96

Note: Products with a label approval for use on protected tomatoes may be used on peppers, subject to restrictions on extension of use under the long term off-label arrangements.

* Assumes two crops per year.

plant for cucumbers. Further dilution occurs as the pesticide breaks down, or is taken up by the plant, and as subsequent irrigations displace the pesticide from the slab. Finally, the pesticide passes through the soil to ground water or finds it way into an underdrainage system and subsequently into a ditch or stream. As mentioned above, the amount of active ingredient remaining depends on how quickly the solution percolates through the soil and hence the opportunity for absorption on organic matter or clay.

The final dilution occurs as the solution containing the a.i. mixes with ground or surface water. Table 3.2.2 gives the lethal concentrations for trout. Carbendazim and etridiazole are far more toxic to fish than propamocarb hydrochloride. If the concentration of a.i. for these two substances is c.20 mg/l as applied, then a dilution factor of about 1:10 would be sufficient to reduce it to below the LC_{50} figure.

A theoretical example of the amount of pesticide which may be applied to and lost from a run-to-waste system is shown below, taking cucumbers and propamocarb hydrochloride as an example.

	Applied [1]	**Loss[2]**
Single application	1.26	0.38 kg ai/ha
Crop total (4 applications)	5.04	1.52 kg ai/ha
National annual totals [3]	705.6	212.8 kg ai/yr

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[1] Assumes Filex is applied at the SOLA rate (1.25 ml/l, 500 ml/plant) and a crop density of 14,000 plants/ha

[2] Assuming a loss of 30% of applied product.

[3] Assuming 80 ha of run-to-waste cucumbers, with 75% of the area re-planted and 4 Filex applications made to each crop.

It must be emphasised that the figures on pesticide loss are a theoretical calculation only and the loss in practice may be considerably different according to various factors including (1) how systemic the pesticide is (2) evapotranspiration rate and root uptake after pesticide application (3) rate of breakdown in water and the interval the pesticide remains in the root zone before further irrigation water is applied. In order to determine the <u>actual</u> loss, time-course studies monitoring the concentration of pesticide in run-off solution at increasing intervals after application, would need to be undertaken.

The concentration of propamocarb hydrochloride as applied is 0.2 mg/l (Table 3.2.1). If this is diluted by the slab solution at a ratio of 1:18, the resultant concentration is 0.011 mg/l (ie 11 µg/l). The MAC for a single pesticide in drinking water is 0.1 µg/l. Therefore the run-off would need to be diluted further at 1:110 to comply with the MAC.

Table 3.22 Persistence and toxicity to fish of active ingredients approved for application to the root zone of hydroponic crops

Product	hemical	omments (1)(2)	Solubility in water (1)	DT_{50} (1)	K_d (1)	K_{oc} (2)	L_{50} for trout (1) (96 hours) mg/l
Filex	Propamocarb hydrochloride	Immobile in soil. Moderately persistent	867 g/l	10-27 days (not specified)	-	10^6	410-616
Derosal WDG and Bavistin FL	Carbendazim (MBC)	Moderately mobile in soil. Very persistent in soil.	mg/l pH 28 4 8 7 7 8	1-5 months (in soil)	-	320	0.36
Aaterra WP	Etridiazole	Slightly mobile in soil. Very persistent. Stable to u.v. light and sun	50 mg/l	103 days (pH 6) (not specified)	5.31 sandy soil 1.41 silt loam	1,000	> 2.66

DT_{50}	Time for 50% loss
K_d	Distribution coefficient between soil and water at one concentration
K_{oc}	Distribution coefficient between soil organic matter (expressed as carbon) and water.
LC_{50}	Concentration required to kill 50% of test organism.

Ref (1) WORTHING, C R & HANCE R J (1992)
(2) WAUCHOPE, R D et al. (1992)

3.22 Pesticide persistence and movement in soil

As the pesticides applied to the root zone are held within plastic in the slab, or underneath it when the solution runs into the soil, there is little opportunity for loss as vapour or for photodegradation. Plant uptake and metabolism will remove a small amount of pesticide; the remainder is potentially available for movement down the soil profile. Pesticide persistence and movement in soils depends on many factors including:

- *The half-life of the chemical (DT_{50}).*
  This is the typical length of time needed for one half of the total amount applied to break down to non-toxic substances. In the UK pesticides are classified into four persistence categories on the basis of DT_{50} by the Pesticides Safety Directorate:

DT_{50} (days)	
< 5	Impersistent
5-21	Slightly persistent
22-60	Moderately persistent
> 60	Very persistent

- *Solubility in water*
- *Microbial degradation*
  Microbial activity is high in warm, moist soils with neutral pH (c. 7.0)
- *Adsorption to clay or organic matter in soil*
  High K_d or K_{oc} indicates greater adsorption by the soil. For most pesticides soil organic matter accounts for most of the sorption, but some may occur on clay.

Some of these factors are given in Table 3.2.2 for chemicals cleared for root zone application to hydroponic crops.

Pesticides that are very water soluble, relatively persistent and not readily adsorbed by soil (low K_{oc} or K_d) have the greatest potential for movement.

3.23 Pesticides found in water

Water companies are required to monitor for pesticides at specified frequencies in samples taken from consumers' taps in each water supply zone. The standard sampling frequency is four samples for each pesticide in each zone. The pesticides to be included in the monitoring programme are not specified. Each company is required to develop a monitoring strategy for pesticides based on the likely risk of particular pesticides being present in the water source serving the zone (Hydes et al., 1992).

During 1989 and 1990, 36 pesticides were detected above 0.1 µg/l (0.03 µg/l for aldrin and dieldrin) in groundwater supplies and 35 pesticides were detected in surface water derived supplies or mixed supplies. Surface water is expected to be more vulnerable to pesticide contamination than ground water because of inputs from spray drift, run-off and field drains. Some of these detections were made on only one occasion and were not confirmed or repeated. Atrazine, simazine, isoproturon, chlorotoluron and mecoprop were detected most frequently in both 1989 and 1990 (these substances are all herbicides).

Fifty-three pesticides were monitored by 20 or more companies (out of a total of 37) or detected above 0.1 µg/l in 1989 or 1990. Of these, 27 were herbicides, 21 were insecticides, 4 were fungicides and one was a wood preservative/disinfectant. The four fungicides did not include any of those cleared for root zone application to hydroponic crops. According to Anglian Water Services, etridiazole might be picked up in a broad screening test as a peak if it were present in sufficient quantities (Clarke 1993, pers. comm.). Water-soluble herbicides are the most commonly reported pesticides found above 0.1 µg/l in water sources (Foster et al., 1991). Atrazine and simazine, the two most commonly reported pesticides in drinking water, have limited use in agriculture but are widely used to control weeds in non-agricultural situations. The more toxic, and less water-soluble, organo-chlorine and organo-phosphorus pesticides are rarely reported.

In a report on pesticides, chemicals and health by the British Medical Association (1990), evidence is quoted of 298 water sources or supplies exceeding the EC Drinking Water MAC for single pesticides (0.1 µg/l) and of 76 breaches of the MAC for total pesticides (0.5 µg/l). The detected breaches occurred in six out of ten of the National Rivers Authority (NRA) regions. It was considered that absence of reported breaches elsewhere may reflect inadequate investigations of water in these areas. In the first report on the quality of drinking water in England and Wales (DoE, 1991) pesticide concentrations above the prescribed standard were found in 2.1% of 540,007 determinations.

As well as the water companies, the NRA routinely analyses for about 50 pesticide active ingredients in fresh waters, but could extend this list relatively easily. However, there will remain some pesticides for which there are no routine methods of detection (NRA, 1992). The three active ingredients approved for root zone application on hydroponic crops are not routinely monitored at present by any of the NRA Regions in either surface or ground water (Eke, 1993 pers comm).

3.24 Risk to the aquatic environment

As well as the possible contamination of drinking water sources, pesticide pollution from hydroponic crops could damage the aquatic environment. Few pesticides are "target specific" and hence affect a range of organisms; the full extent of their toxicity to a range of aquatic life is usually unknown (NRA, 1992).

Pesticide contamination of watercourses largely depends on pesticide mobility in soil, solubility and rate of degradation. Although many pesticides decompose quickly in the soil, it is likely that they will be more persistent once in the ground water because this tends to be less biologically active (NRA, op cit). Pesticide degradation in surface water occurs by direct sunlight-induced reactions or reactions with photochemically produced reactive chemical transients eg OH-, superoxide or carbonate (Zepp, 1991).

Discharges from point sources (eg drain outfalls into dykes or streams) can result in fish and invertebrate mortalities.

Risks to the aquatic environment also arise from the storage of pesticides. The disposal of even small amounts of unused or surplus pesticide to foul sewers is another area of concern to the NRA. The pesticide may pass through the sewage treatment process unaltered and enter the river where it may kill aquatic life. In addition, the toxicity of some compounds is such that a relatively small amount could impair or incapacitate the biological sewage treatment process, and the discharge of inadequately treated sewage might then also pollute the river (NRA, op cit). The Code of Practice for the Safe Use of Pesticides on Farms and Holdings (1990) gives guidance on pesticide use and precautions to be taken to prevent water pollution.

4. A COMPARISON OF SOIL NUTRIENT CONTENTS UNDER ROCKWOOL AND SOIL-GROWN CUCUMBERS AND TOMATOES

4. COMPARISON OF SOIL NUTRIENT CONTENTS UNDER ROCKWOOL AND SOIL GROWN CUCUMBERS AND TOMATOES

This section draws together results from MAFF-funded work comparing soil mineral N levels under rockwool and soil-grown cucumber crops and new results from similar studies after rockwool and soil-grown tomatoes. Soil samples from the original MAFF-funded survey were used for additional analyses for a range of nutrients.

There were three sites:-

1. HRI Stockbridge House
   House 8 and adjacent grassed area outside.

2. Commercial cucumber nurseries, Lea Valley

   (i) Rockwool

   (ii) Soil

3. Commercial tomato nursery, Cambridgeshire

   (i) Rockwool

   (ii) Soil

In Lea Valley, the rockwool and soil-grown crops belonged to different nurseries, but they were next to each other and on the same soil type.

At Stockbridge House, House 8 had been under rockwool for 10-12 years at the time of sampling. An adjacent grassed area outside was sampled for comparison. At the tomato nursery rockwool and soil crops could be sampled on the same site.

4.1 Methods

At Stockbridge House, three transects were made, perpendicular to the ridges, of 17 samples each (total 51). Half of these were in the centre of the paths and half were taken between the double rows . Samples were taken to four depths at each sample point:

0-15 cm
15-30 cm
30-60 cm
60-90 cm

Three cores were taken at each depth and bulked together to give sufficient sample. Twenty cores were also taken from an adjacent grassed area at each of the above depths and bulked together. Samples were taken in November 1989.

At the Lea Valley rockwool site 5 transects were made of 10 samples each, perpendicular to the ridges, half in the centre of the paths and half between the double rows, as at Stockbridge House. Exactly the same procedure was followed for the soil house. The samples were taken at the end of October 1989, straight after the crops were removed.

The rockwool tomato house at the Cambridgeshire site had had rockwool crops for more than ten years at the time of sampling (28 + 29.10.92). The soil house had had tomato crops since the mid-70's. For both the rockwool and the soil houses, two samples were taken from the path areas and two from between the double rows, to the same depths as in the previous studies. Each depth sample consisted of ten cores, bulked together.

A "mini-transect" was also made in each house consisting of seven samples right across the path and where the rockwool had been to a depth of 15 cm only.

All the samples were analysed for soil mineral N (Anon, 1986), which is carried out on fresh soil and measures the nitrate and ammonium-N in the soil (ie the fractions not bound up in organic matter or biomass). Soil mineral N concentrations were converted to quantities (kg/ha N) down to 90 cm assuming a bulk density of 1.33 g/ml. Topsoil (0-15 cm) samples were also analysed for the normal ADAS glasshouse suite of determinations (nitrate-N, conductivity, phosphorus, potassium, magnesium and pH; Anon, op cit). This was carried out after the samples had been dried and ground in the normal way. Soils were also analysed for boron and zinc (Anon, op cit). The 1989 samples were bulked together to form two bulked samples from path areas and two from between the rows for each site. These were analysed for the additional nutrients as above.

4.2 Results

Results of all the soil analyses are given in Table 4.1.

4.3 Discussion

Mean soil mineral N values measured under rockwool cucumbers at Stockbridge House were similar to average values found for fields receiving pig or cattle FYM, or where grass had been ploughed out 6-10 years previously (Table 4.2).

Soil mineral N values under a rockwool tomato crop were 72% higher than for the Stockbridge House rockwool cucumber site. This was expected as until recent developments with chloride-based feeds the recommended N levels were c.400 mg/l for tomatoes for the first four months of the season, dropping to about 250 mg/l for the remainder, compared with 180 mg/l as the target applied value for cucumbers throughout the season. Soil mineral N values measured under a rockwool tomato crop were similar to average values found for fields receiving pig slurry or poultry manure (Table 4.2).

If the soils in the present study were classified according to the system applied to arable cropping rotations then the Stockbridge House site would be classed as "moderately high", the Cambridgeshire rockwool tomato site as "high" and the other three sites as "extremely high". (See Table 4.3 for details).

Table 4.1 Soil Analyses

Site			mineral N * kg/ha	Nitrate-N mg/l (index)	Phosphorus mg/l (index)	Potassium mg/l (index)	Magnesium mg/l (index)	Conductivity µs (index)	pH	Ext Zn mg/l	B ext. total mg/ kg
HRI Stockbridge House Cucumbers	H8 (rockwool)	Path	251	278(5)	68(4)	969(6)	274(5)	3235(6)	6.4	19	0.6 1.6
		Row	97	88 (2)	127(6)	636(5)	151(3)	2460(2)	6.0	25	0.6
		Mean	170	183 (4)	98 (5)	803(5)	213(4)	2848(5)	6.2	22	0.6
	grassed area (outside)		16	7 (0)	47(4)	127(2)	94(2)	2100(0)	6.5	25	0.5
Lea Valley Cucumbers	Rockwool	Path	1319	191(4)	57(4)	376(3)	439(6)	2930(5)	7.0	137	2.4
		Row	712	76(2)	121(6)	879(5)	349(5)	2555(2)	6.8	109	1.5
		Mean	1015	134(3)	89(5)	628(5)	394(6)	2743(4)	6.9	123	2.0
	Soil	Path	891	121(3)	27(3)	198(2)	417(6)	2550(2)	6.8	84	1.6 2.0
		Row	939	112(3)	25(2)	199(2)	421(6)	2610(3)	6.9	80	2.1
		Mean	915	117(3)	26(3)	199(2)	419(6)	2580(2)	6.9	82	1.9
Cambridgeshire tomatoes	Rockwool	Path	230	32(1)	136(6)	1296(6)	315(5)	2750(4)	7.2	30	27
		Row	356	60(2)	206(8)	1258(6)	258(5)	2500(2)	7.3	37	20
		Mean	293	46(1)	171(7)	1277(6)	287(5)	2625(3)	7.3	34	24
	Soil	Path	967	88(2)	95(5)	733(5)	755(7)	3095(6)	6.2	46	17
		Row	1177	100(2)	81(5)	796(5)	416(6)	2645(3)	4.9	47	15
		Mean	1072	94(2)	88(5)	765(5)	586(6)	2870(5)	5.6	47	16

* 0-90 cm

Table 4.2 Typical soil mineral N values

	Soil mineral N kg/ha (to 90 cm)
	Autumn
Unfertilised grass (1)	20-40
Intensive grass (2)	80-150
Arable Crops (3)	
Wheat	94
Barley	84
Sugar beet	54
Beans	95
Peas	110
Oilseed Rape	134
Potatoes	115
Field Veg (4)	
early Summer cauliflowers	230
sprouts	35-50
Organic Manures (5)	
Pig Slurry	310
Poultry manure	271
Sewage sludge	219
Cattle slurry	226
Cattle FYM	179
Pig FYM	147
Grassland (5)	
1-5 years ploughed out	212
6-10 years ploughed out	168

Fruit (6)	Row	Alley	Row	Alley
Apples, dessert & culinary	126	107	114	106
plums, raspberries & strawberries				
pears & blackcurrants	286	153	242	127
	Row	Path		

Cucumbers (7)	Rockwool	405	785
	Soil	939	891
Tomatoes (8)	Rockwool	356	230
	Soil	1177	967

(1) Lord, 1994 (pers. comm.)
(2) Dampney, P M R 1994, pers comm (ADAS data).
(3) Chambers, B J 1994, pers comm (ADAS data)
(4) Rahn, CRR (1993)
(5) Chambers, B J 1994 pers comm (ADAS data)
(6) Marks, M J (in press)
(7) Vaughan, J (1989) Nutrient residues under rockwool and soil-based cucumber crops (MAFF-funded).
(8) Data from present HDC project.

Results for the cucumber rockwool site in Lea Valley are six times higher than for the Stockbridge House site. The mean value for the Lea Valley rockwool crop is only 11% higher than for the soil crop. Values measured under the tomato soil crop are even higher. It is possible that the soil mineral N levels for the Lea Valley rockwool cucumber crop reflect values that would have been present when the house was converted from soil to rockwool in 1986. The Stockbridge site had been rockwool for 10-12 years at the time of sampling and the tomato site had also had a rockwool crop for at least ten years.

The target value for soil-grown tomatoes is 50 mg/l of nitrate-N (analysis on dried, ground sample). The recommended N level for soil-grown cucumbers is the same. The actual mean values measured by this method were 117 mg/l NO_3 -N for the Lea Valley cucumber soil crop and 94 mg/l for the soil-grown tomato crop.

The recommended liquid feeds for soil-grown crops are 170-225 mg/l N for cucumbers and 180 mg/l N for tomatoes. The results for soil-grown crops in this study thus appear to represent a considerable accummulation of soil mineral N, both in the top 15cm and down the profile to 90 cm (see Appendix III), or applications in excess of recommended levels.

Table 4.3 Classification of soil mineral N figures in arable cropping rotations

Soil mineral N 0-90 cm (kg/ha)	**Classification**	**Interpretation**
121-200	MODERATELY HIGH	Typical of fields in moderate/high N Index 1 residue situations, previous cropping/management: - oilseed rape - beans/peas (high N fixing situations) - potatoes, generally non irrigated - fields receiving FYM, sewage sludge, or low rates of slurry/poultry manure - vegetables receiving >200 kg/ha N - long leys, cut or grazed + low N
201-300 301-500 > 500	HIGH) VERY HIGH)) EXTREMELY HIGH)	Typical of fields in N Index 2 situations, previous cropping/management: - fields receiving regular and/or large dressings of FYM, sewage sludge, slurry or poultry manure - fields with elevated organic matter levels (peaty soils) - long leys, cut/grazed + high N - permanent pasture

(after Chambers)

Soil mineral NO_3-N (0-15) cm was compared to NO_3 -N measured by electrode for the same depth (Fig 4.1). This was for the tomato site only as results for the two cucumber sites were not strictly comparable (see Section 4.1). As would be expected, there is a poorer correlation between the calculated soil mineral N to 90 cm (including ammonium-N) and the NO_3-N measured by electrode in the 0-15 cm horizon (Fig 4.2). Nevertheless, values obtained by the electrode method used by ADAS for routine glasshouse soil analysis could be used to predict whether other glasshouse crops would be likely to leave low or high levels of soil mineral N.

"Mini-transects" were made right across the soil under the double plant rows and the path (Fig 4.3). Results show that for the rockwool tomato crop, soil mineral N values (0-15 cm) were about twice as high in the middle of the double row as in the middle of the path (Fig 4.3a). Values for the soil transect were similar for the path and row areas (Fig 4.3b).

Mean values for the path samples under rockwool cucumber crops are roughly twice those measured under the rows (Table 4.1). For the rockwool tomato crop the mean row value is 1.5 times greater than the path mean. It might have been expected that there would be a nutrient enriched zone beneath the rows. The soil in a rockwool crop is covered with polythene and there should be little evaporation from the path area. However, after the crop has been pulled out, the polythene is discarded. During the period before new polythene is laid, the soil dries out and mobile ions such as nitrate may move laterally towards drier soil under the paths. Another possibility is that the soil is uniformly high in nutrients after a series of soil-grown crops. The soil is not leached when the transition to rockwool is made so the nutrients remain. Subsequent leaching of excess rockwool solution may reduce the nutrient content under the gutters until it reaches some sort of equilibrium with the rockwool solution passing through.

It is possible that some nitrogen is being lost through denitrification (see Section 3.16). The soil in a glasshouse will be at or above 18°C for much of the year and may be considerably higher than this in the summer, at least in the surface layer. The soil under the double rows is very moist, if not saturated, and could well be anaerobic under the polythene. Some rockwool crops are grown on peaty soils (eg parts of Lancashire). Many glasshouse soils have higher organic matter contents than the average arable soil

Fig 4.1 Relationship between soil mineral Nitrate - N and Nitrate N measured by electrode 0 - 15 cm for two tomato crops.

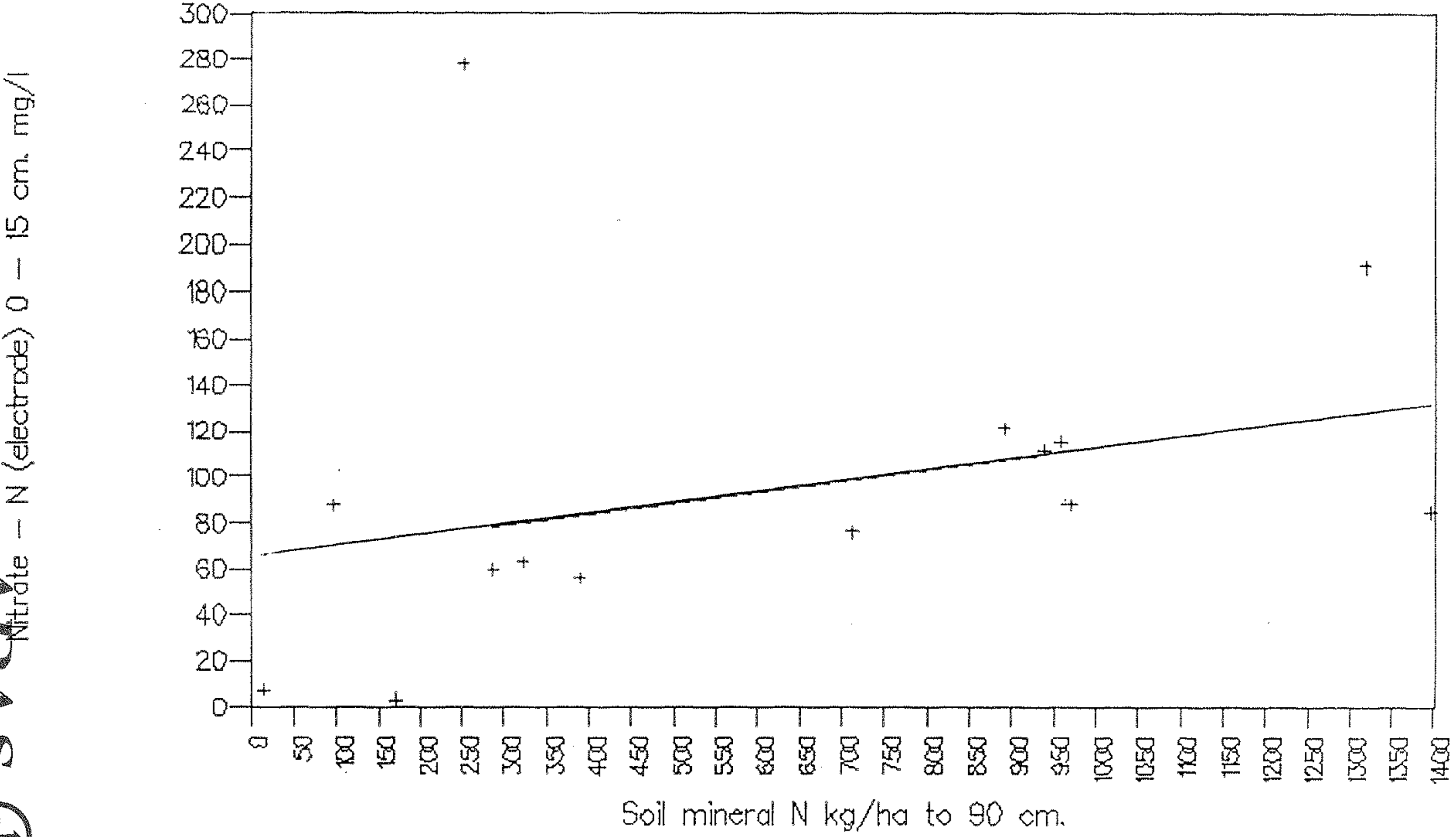


Fig 4.2 Relationship between soil mineral N (0 - 90 cm) and Nitrate N measured by electrode (0 - 15 cm).

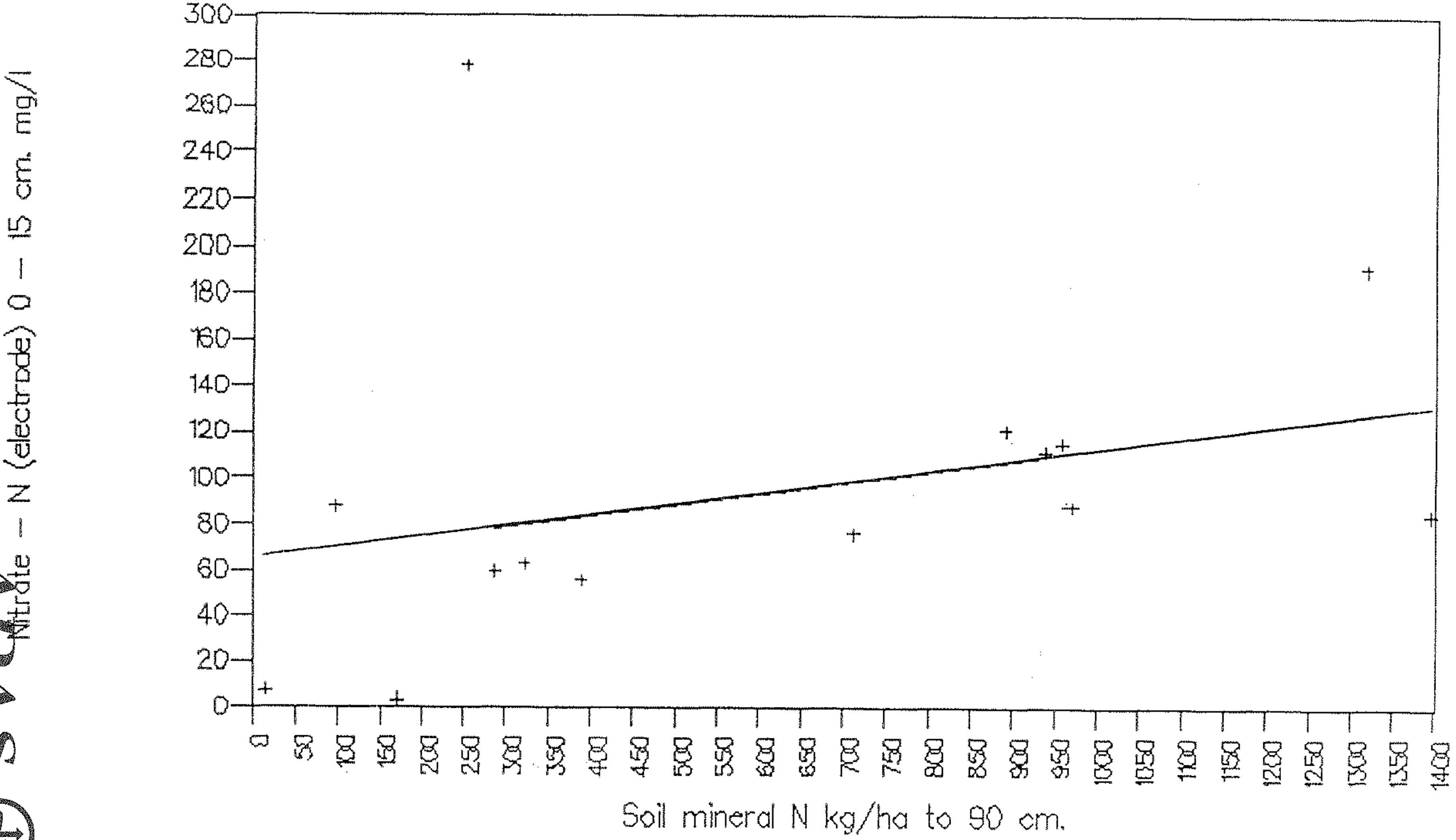


Fig 4.3 (a) Rockwool Transect 0 - 15 cm. Soil Mineral N.

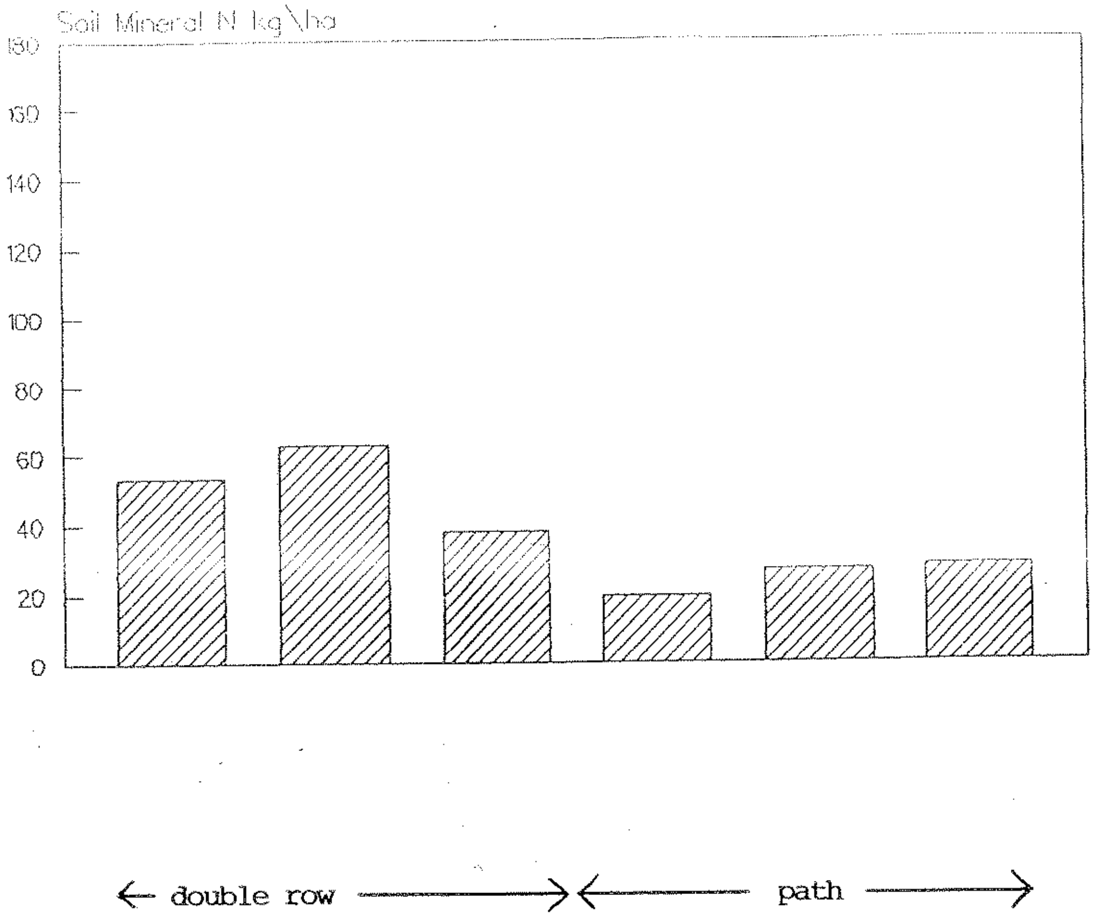
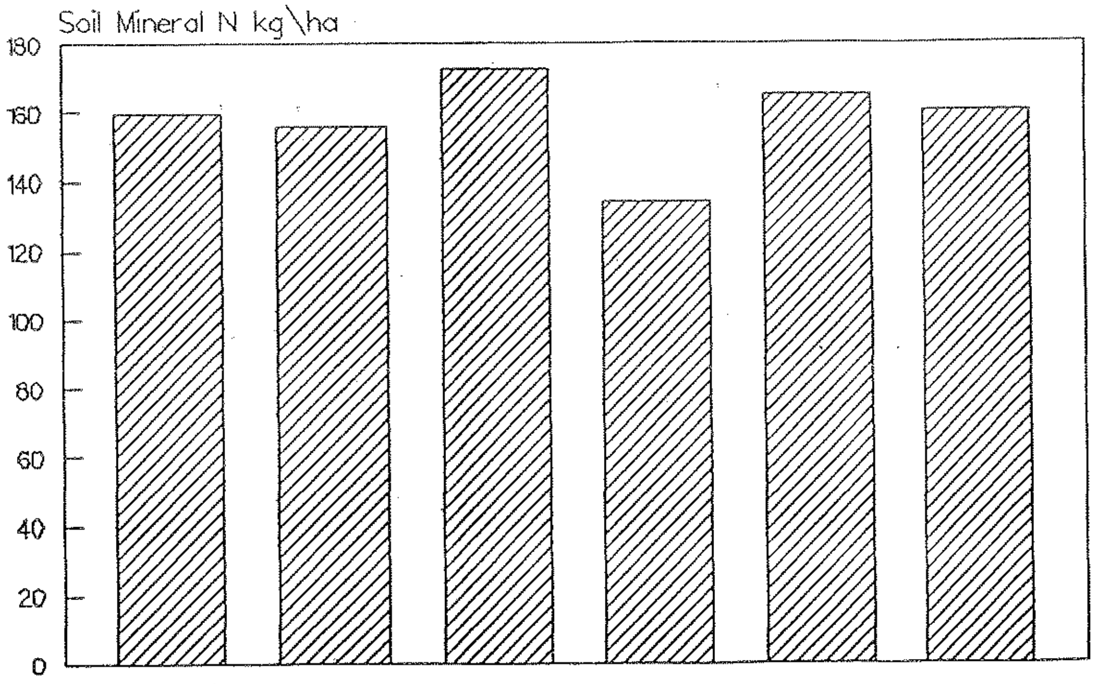


Fig 4.3 (b). Soil transect 0 - 15 cm. Soil Mineral N.



ADAS

due to the incorporation of peat blocks used for propagation, and in some cases incorporation of peat or straw bales in previous years. The large amounts of nitrate-N available would favour the production of nitrous oxide (N_2O) as well as nitrogen.

The *potential* for loss of nitrate-N is high if the soil is subsequently leached. This is sometimes carried out if lettuce is grown after tomatoes in the soil. It has been estimated that to reduce the soil NO_3-N by 100 mg/l 0-15 cm (electrode method) would result in a leaching loss of 150 kg N/ha. Of course, some of this would move downn the soil profile, but a proportion would be lost, especially if the leaching were repeated every year. For rockwool crops, much NO_3 -N is lost in run-off, as well as leaving high residues in the soil (see Section 5).

The results presented in this section are taken from only five crops. A more extensive survey would be needed to see if the results presented here are typical of the industry, but soil mineral N values for cucumbers and tomatoes grown in rockwool or soil are likely to be much higher than most arable crops because very much larger amounts of fertiliser N are applied than are removed by the crop.

First results from new research on phosphorus in soils have indicated that phosphorus may be more mobile than previously thought. There may be considerable risk of P leaching at Soil Index 5 and above (Withers, 1994, pers. comm.).

Two trace elements were also measured. Zinc was chosen because it is added to hydroponic feeds at higher concentrations than other trace elements except iron. Iron is present in large quantities in soils and is unlikely to cause a problem. Archer and Hodgson (1987) measured total and extractable trace element contents of randomly selected agricultural fields throughout England and Wales. Ninety-five per cent of samples had EDTA-extractable zinc values in the range 1.5-21 mg/l. The median value was 5.4 mg/l. The levels measured in the present study were higher than this, particularly for the Lea Valley rockwool site. The mean for the `path' sample was 137 mg/l. Toxicity is possible in sensitive crops at this level (Anon, 1981). Since the zinc levels found under the rockwool tomato crops only averaged 34 mg/l, it is possible that the Lea Valley site had been contaminated in some way. Greenhouses are made of galvanised steel and it is possible that condensation on the structure deposits zinc as it reaches the soil.

As part of the Harmonised Monitoring Scheme, zinc is monitored regularly at river locations all over Great Britain. Twenty-seven per cent of samples have a zinc concentration greater than 0.03 mg/l zinc, the rest are below this value (DoE, 1993). The guide level for zinc set by the Drinking Water Directive (1980) is 0.1 mg/l "at outlets of pumping and/or treatment works and their substations". However 5 mg/l Zn is the guide level after the water has been standing for 12 hours in the piping and at the point where the water is made available to the consumer. No maximum admissible concentration is defined.

The recommended zinc levels for hydroponic crops are 0.5 (cucumbers and peppers) and 1.0 mg/l for tomatoes (Vaughan 1988, 1991; Ashdown, 1991). Therefore, dilution factors of 5 and 10 respectively would be sufficient to meet the lower guide level.

Due to an error when the tomato site soils were submitted for analysis, total boron was measured instead of extractable boron. However, the total soil boron contents reported by Archer and Hodgson (op cit) ranged from 7-119 mg/kg around a median of 34 mg/kg. All total boron values in the present study were less than this median. Extractable boron values in agricultural soils ranged from 0.1-11.7 mg/l with a median of 1.1 mg/l (Archer and Hodgson, op cit). Values measured in the present study were very low at Stockbridge House (0.5-0.6). Susceptible crops may develop boron deficiency at this level. Results from the Lea Valley sites ranged from 1.5 to 2.4 mg/l./ The Guide level for boron in drinking water is 1.0 mg/l. The levels recommended for hydroponic crops are 0.3 cucumbers, 0.4 tomatoes, and 0.5 peppers (Vaughan, 1989, 1991; Ashdown, 1991).

5. CASE STUDIES

Table 5.1 **Background details**

	1	2	3	4	5	6	7
Crop and Type of System	run-to-waste rockwool tomatoes	recirculating rockwool peppers	run-to-waste rockwool cucumbers	NFT tomatoes	run-to-waste rockwool tomatoes	run-to-waste rockwool tomatoes	run-to-waste rockwool cucumbers
Mean annual rainfall mm	726	717	621	635	857	604	611
Size of nursery ha	4.51	5.18	1.62	?	1.80	2.40	10.12
Type of glasshouse	Wilco Double Venlo	6.4m Double-span Venlo	Cambridge 30' x 200' Wright Rain 22' x 200' Hancock 14' x 213'		Wilco	HOK 3.2m bay Venlo 2.4m to gutter	Venlo
Approx date		1989		1989			

5.2 **Drainage**

Of the five nurseries with run-to-waste systems, four had tiled or plastic underdrainage systems and one grower thought there were probably old tile drains. The NFT nursery also had a tiled underdrainage system. Four out of seven growers knew where their outfalls were. Two systems drained into ditches or dykes close to the nursery, one into a lagoon and one into a stream.

5.3 **Water Supply**

Table 5.3 summarises the details of water supply and consumption; four growers were using mains water, one borehole, one mainly reservoir and one river. Costs for mains water ranged from 34.4p/cu.m to 57p/cu.m (1992 prices). Taking a typical water consumption figure of 1550 l/m^2/year, this means the cost of water would vary from £5,332 to £8,835 per ha. Variable costs (production) for December planted rockwool tomatoes are estimated at £101,920/ha excluding marketing, (ADAS Gross Margin Budgets: 1992). The cost of mains water therefore represents about 5-9% of those costs. This makes building a reservoir an attractive option. Nursery No 5 constructed a clay-lined reservoir of 13,600 cu.m capacity for approximately £20,000. This supplied 95% of the water for 1.8 ha of rockwool tomatoes by collecting roof water. This nursery is in a relatively high rainfall area (857 mm) compared to a range of about 600-730mm for other major growing areas.

Table 5.3 Water supply

		1	2	3	4	5	6	7	x̄
Source		Mains	Mains	Borehole	Mains	Reservoir 95% Mains 5%	Mains	River	
Costs: Mains	£/cu m (1,000 litres)	0.344 1992	0.407 1992	-	0.571 1992	0.464 1992	0.540 1992		0.465
Borehole/ River	Abstraction Licence Running Costs	- -	- -	- -			- -	£ 250 £1,000	
Reservoir	Description	-	not covered	-		clay-lined not covered	PVC lined not covered	not covered	
	Cost of construction	-	-	-		£20,000 approx	£20,000	-	
	Running costs	-	-	-			£1/hour when in use	-	
	Capacity cu.m	-	9,600 minimum	-		13,600	9,100	500	
Water Treatment	See text for details	Filters	None	Filters	None	Filters + heated to 20°C	Filter	Settle-ment + filters	
Consumption	Litres/m²/year data source	1548 water meter	1289 (estimate)	Not known	663 water meter		2080 water meter	1033	

However, even allowing for a butyl rubber or polythene liner, the simple pay-back period would be less than three years. A few growers may be close enough to a suitable river or stream for water to be taken from the river in winter and stored in a reservoir. The cost of the National Rivers Authority licence charge will be about a tenth of that for abstracting from a river during summer (Pearce, 1992). Spray irrigation licences allow the NRA to restrict or ban abstraction at short notice but glasshouse growers have an exemption under the Spray Irrigation Order (1965). It may be difficult to get new or increased volume extraction licences in problem areas. Not all growers have sufficient land to build a reservoir. There are also possible risks from herbicide drift from adjacent arable land contaminating the reservoir or of fungal pathogens such as phytophthora and pythium occurring in it.

The two growers using water from an uncovered reservoir or river water were not treating the water to reduce or remove pathogens. Grower 2 who was re-circulating the solution from February onwards also used no water treatment.

5.4 Irrigation

As expected, there were large differences between growers in terms of irrigation policy, water consumption and estimated run-off. The questionnaire was very detailed in this area, in the hope that some explanation could be found for this variability. The rockwool growers can be divided into two groups according to estimated percentage run-off:

	Group A	**Group B**
Case-Study No	2, 3, 5, 7	1, 6
Estimated run-off (%)	25-35	50-60

Variability was correlated with output of nozzles; growers 2 and 7 reported 10% variation between drips. Number 7 had a relatively new design of dripper with a grooved stick inserted into a capillary tube. These are relatively simple to clean and to unblock but it is less easy to see whether or not they are dripping. However, the high output (5 litres/hour nominal) may mean they block less frequently. Grower 6 reported 20% variability by the end of the season from 3 litres/hr plain capillary tubing. Grower 5 estimated up to 50% variability from drips with a very low output (1 litre/hour). Grower 1 quoted variability of ± 25% from the nominal output of 2 litres/hour so the maximum difference between two drippers could be 50%.

Growers 1, 5 and 6 were working with a minimum quantity of 100-175 mls/watering. Of the two growers who claimed 10% variability between drippers one could reliably apply 75mls/watering whilst the other used 200mls. Grower 3 did not know what the variability was and used a minimum of 250 mls per watering. Clearly, a large difference in output between individual drippers limits the scope for reducing run-off. If a grower has to water for the driest plants those plants with drippers working adequately will be receiving too much. From this survey it appears that 10% variability is the best that can be achieved at present.
Some plants will be drier than others due to position. For example, those at the ends of rows, particularly south-facing gables, need extra drippers.

Growers were also asked what action they took to reduce blockages in drips. One grower with 50% variation replaced the whole system for the next crop. Growers 2, 3 and 5 used nitric acid at the end of the season; grower 2 also used hypochlorite and grower 3 high-pressure water. Grower 6 used high pressure water. Grower 7 checked every nozzle every four weeks and flushed through the lines after taking the end bungs off. He reported bacterial slime as the main problem and used sodium hypochlorite at the end of the season. The accepted treatment is to use both nitric acid (to remove limescale) and hypochlorite to remove organic deposits.

Grower 3 watered on a timed basis only: up to three times per hour in the period 12.00-14.00 hours. At other periods there was up to two hours between watering. He also watered once at midnight. The maximum applied in one day was 5 litres but the plant population was low: 4,750 plants/acre (11,737/ha). The other cucumber grower (No 7) also applied a maximum of 5 litres/plant/day (5,600 plants/acre; 13,838/ha).

All the other rockwool growers used a combination of timed and radiation starts. Grower 1 reduced the interval between waterings depending on the amount of light received up to a maximum of 22 starts per day (but no night watering). The maximum applied in one day was 3.85 litres.

Grower 2 used timed starts for the first month (mid October-mid November) followed by radiation starts with fine tuning. Re-circulation commenced in February. The conductivity of the run-off was monitored and the volume per watering increased if the EC exceeded a set threshold. Red peppers were irrigated twice a night in good weather conditions. The maximum applied per plant per day was 3.3 litres.

Grower 5 watered 150 mls each two hours dawn to dusk in mid-summer plus radiation starts up to a maximum of 3 litres/plant/day. Night watering was only used in the early season.

Grower 6 used timed waterings until the plant was placed in contact with the slab. Thereafter timed starts were used hourly from 04.00-07.00 hours followed by radiation starts until 16.00-17.00 hours.

This policy resulted in a maximum of 40 waterings in 24 hours - far more than any other grower in the survey. The maximum applied per plant per day was the highest of the rockwool tomato growers (4.0 litres).

Grower 7 used timed starts from planting (4 December) up to March, then radiation. This grower had the lowest maximum number of waterings per day for rockwool (15). The foam slabs had to be irrigated more frequently (25-30 times per day). The foam was also given one night watering but the rockwool was not.

The number of megajoules used to trigger a watering varied between growers. Grower 2, who was in the low run-off group, used 100 MJ between 11.00 and 15.00 hours and 120 MJ at other times. These figures could be reduced by 40 MJ depending on the amount of drainage. Grower 5 used only 90 MJ to trigger a watering. Grower 6 used 70 MJ to trigger 100 mls between 10.00 and 14.00 hours then 100 MJ between 14.00 and 16.00 hours. Grower 7 used 125 MJ per watering in summer.

Table 5.4 Irrigation

		1	2	3	4	5	6	7	$\bar{x}$
Description of equipment	Type of fertilizer mixer	Van Vliet with mixing tank	Tebarint Injection	Vocom 203/204		Baggley Injectors	Priva	Vocoms	
	No of valves per group	4	12	Varies		6	6/8	3	
	Make of trickle harness	VanHecke (Brinkman)	Wetering	Brinkman		Fording-bridge	Capillaire	Drip stick	
	Type of nozzles	Capillary tube 0.9mm bore	Wetering	Capillary tubing		Fording-bridge	Plain tubing	Grooves	
	Output (litres /hour)	2	2	3		1	3	5	
	Variability	± 25%	10% (start of season)	-		Up to 50%	20% end season	10%	
Irrigation policy (see Text for details)		Timed plus light reduction	Timed for 1st month then radiation	Timed		Timed	Timed/ radiation combined	Timed until March then radiation	
No of MJ to trigger a watering		-	120/100	-		90	70/100	125	
Max No of irrigations in 24 hours		22		-		16 (mean)	40	15	
No of night waterings		None	2 (max)	1		None in summer	None	1 (max)	
Maximum applied in one day (litres)		3.85	3.30	5.0		3.0	4.0	5.0	4.0
Minimum quantity which can be applied reliably at one watering (mls)		100	75	250		150	100	200	
Action taken to reduce blockages in drips		Replace irrigation	Nitric acid hypochlorite	Nitric acid + hp water		Nitric acid	hp water	hypochlorite	
Run-off	Method of monitoring	Whole row	At return tanks	Tray with 2 plants x 4 valves		Buckets 5/ha	?	20 points	
	Volume (as % of applied solution)	50-60	30	25-30		25-30	50	25-35	
	Is EC of run-off monitored?	Yes	Yes			No	?		
Policy on "bleeding" and/or dumping" (NFT only)		-	-	-	None	-	-	-	
Criteria for flushing (rockwool only)		None	None	-		Slab EC	if required	EC & SO4 limits	
Method of flushing		Not done	Not required	Rarely		?	inc vol per watering	1 hour cont watering	

Table 5.4 (cont)

	1	2	3	4	5	6	7	$\bar{x}$
Solarimeter data Type	Kipps	Kipps	Not used		Kipps	Kipps		
Units per season J/cm²				3429 MJ/m² Total			891 av J/m²	
Water Consumption litres/m²/year	1548	1289		663		2083	1033	
Substrate type: make/density	Capogro Low density	Grodan High density	Grodan High density	NFT	Capogro High density	Capogro ? density	Grodan and Aggro-foam	
Frequency of analyses	monthly	weekly	every 2 weeks	every 2 weeks	every 2 weeks	Monthly (drips only)	Every 6 weeks	

5.5 Run-off and Nutrient Loss

All six rockwool growers had some means of monitoring run-off. Grower 1 was able to monitor the volume and EC of the run-off from a whole row of tomatoes in each quarter of the block. The grower with a re-circulated rockwool system (No 2) monitored the volume and EC at the return tanks. Grower 3 used a tray to collect the run-off from two cucumber plants for each of the four valve groups. He also used a spare dripper to record the amount applied. These points were monitored each day at mid-day. Grower 5 also used buckets to collect run-off at two per acre (5 per ha) and checked them at the same time each day. Grower 7 measured run-off at 20 points (0.8 per acre; 2.0 per ha).

As discussed above, the output of individual drippers may vary by 10-50%. The water consumption of plants also varies due to factors such as site, vigour and whether a side-shoot has been taken (tomatoes). Therefore, it was necessary to try and estimate run-off by another method in order to corroborate the growers' measurements.

Firstly, the growers were asked for total water consumption figures. Three growers (1, 4 and 6) used only mains water and therefore had a very accurate record of water used. The quantities were 1548, 663 and 2083 litres/m²/year respectively. Grower 4 had an NFT system. Growers 1 and 6, both in rockwool, claimed run-off figures of 50-60%. Both grew tomatoes but although Grower 6 sowed nearly a week later than Grower 1's latest sowing date and picked 30 tons/ac (75 t/ha) less tomatoes he still used 535 litres/m² more water. Therefore, both estimates of run-off cannot be correct. This subject is discussed in greater depth in Section 9 using estimates of crop water use.

Grower 7 (cucumbers) claimed to use only 1033 l/m^2. The other cucumber grower (No 3) used a borehole and had no estimate of water used. Grower 5 used rain water from a reservoir so an attempt could be made to estimate water use from rainfall data, the area of glasshouse roof and the volume of the reservoir.

Sometimes the concentration of nutrients in the rockwool slab solution differ widely from the recommended values. This is because some elements tend to be depleted (eg nitrate - N and potassium) whilst others accumulate (sodium, chloride, sulphate, calcium and magnesium). One of the methods of restoring the balance of nutrients is to flush the slabs with solution having the correct composition. This practice can lead to large amounts of run-off over a short period.

Tomatoes are grown at higher conductivities during the early part of the season (5,000-6,000 μs); this must be reduced to about 2,500-3,000 to correspond with the start of picking. This is usually achieved by starting to reduce the conductivity of the applied solution 2-3 weeks before picking. However, occasionally the conductivity does not decline quickly enough, possibly because very little irrigation is required, and then flushing may be used.

Growers in the survey were asked what criteria they used to decide whether to flush and how they flushed the slabs. Growers 1 and 2 never flushed their slabs and Grower 3 only rarely. Grower 5 used slab EC and nutrient analysis to decide whether flushing was required. Grower 6 only flushed during March/April if needed ie to reduce the slab conductivity from the early season to the main season range. This was achieved by increasing the amount per watering to 150 mls. Grower 7 used a quite specific criterion to decide when to flush: sulphate-S greater than 100 mg/l. Flushing was achieved with 1 hours continuous watering which in this case was 5 litres per plant.

5.6 Substrate

Growers 2, 3 and 7 used high density Grodan. Grower 1 used low density Capogro. The low density materials are designed to be used for one season and then discarded; high density materials can be sterilised then re-used. There was no apparent relationship between the type and density of product and the amount of run-off, although Capogro is reported to be freer-draining than Grodan(? trials evidence). Grower 7 was also using a foam slab ("Aggrofoam") which it is claimed can be re-used for up to ten years. The foam required a maximum of 25-30 irrigations per 24 hours, compared to only 15 for the Grodan rockwool. Run-off was also higher for the foam slabs (30-35% compared to 25-30% for rockwool).

The NFT nursery had rows 35m long with a slope of 1 in 80 and a flow rate of 5 litres per minute.

5.7 Nutrition

The applied, slab or NFT solution target ranges are given in Table 4 below:

Table 5.71 Applied, slab or NFT solution conductivity ranges (MS)

Grower No	Crop	Early (up to March/April)		Main		Late Sept onwards	
		Applied	Slab/solution	Applied	Slab/solution	Applied	Slab/solution
1	Tomatoes	4.0-5.0		2.5-3.0		3.5-4.0	
2	Peppers	3.1	3.4-3.5*	2.3-2.5	2.8-3.3*	2.3-2.5	2.9-3.4*
3	Cucumbers	3.0	2.9	3.0	3.6	3.0	3.8
4	Tomatoes	5.0-7.0	5.0-7.0	3.0-3.5	3.0-3.5	3.0-3.5	3.0-3.5
5	Tomatoes	4.5	5.5	2.2-2.8	3.5-4.0	3.0	4.0-4.5
6	Tomatoes	4.5	5.0-6.0	2.5-3.0	3.0-3.5	3.5	4.0-5.0
7	Cucumbers	2.5	2.5	2.2	2.0-2.3	1.9	2.0-2.3

* Drain solution

Typically, tomatoes were grown at 4.0-5.0 mS applied, 5.5-6.0 in the slab until March/early April. During the main part of the season the applied range was 2.5-3.0 mS with a light reduction to 2.2 or 2.3; corresponding slab values were 3.0-4.0 mS. Peppers and cucumbers were grown at lower

EC values. For peppers the slabs were wetted-up at 3.1 mS and the applied solution EC varied between 2.3 and 2.5 depending on whether the peppers were orange/yellow or red varieties. The pepper nursery recorded the nutrient content of the drain solution which was recycled. Grower 7 applied solution in the range 1.9-2.5 mS depending on the time of year and slab values were in the range 2.0-2.5 mS. Grower 3 applied solution at a constant 3.0 mS but slab values ranged from 2.9 in March/April to 3.6-3.8 in the main and late season. Most cucumber growers would be using lower EC's than Grower 7.

The frequency at which growers sent samples to laboratories for a complete analysis varied from every week (Grower 2) to every 6 weeks or not at all from some blocks (Grower 7). No growers had any leaf or sap analysis done.

Some growers were able to supply details of all the fertilizer they had used in the season. Where details of water consumption were available as well the theoretical mean concentration of nutrients could be calculated (Table 5.7.2). This includes any nutrients in the water.

For Grower 1 the calculated values are similar to the mean of feed analyses, apart from phosphorous. In the case of Grower 2, the nutrient concentrations in the drain solution are higher than those in the applied feed, except for phosphorous. This means there should be scope for reducing the inputs.

Grower 3 had samples analysed every two weeks from March to July plus one in September. This cucumber grower had the highest mean concentration of nitrate-N in the survey.

Grower 6 (tomatoes) had low concentrations when calculated from fertilizer and water consumption

Table 5.7.2 **Mean solution nutrient concentrations**

(a) Major Elements

Grower No	Crop	Description	NO_3- N	P	mg/l K	Ca	Mg	Cl	SO_4-S
1	Tomatoes	Calculated	209	57	405	198	57	177	81
		Feed mean	225	35	431	194	61	141	-
2	Peppers	Feed mean	232	33	226	238	37	-	-
		Drain mean	319	28	240	362	56	-	-
3	Cucumbers	Slab mean	334	46	323	367	87	35	127
4	Tomatoes	Tank mean	205	43	305	318	90	642*	
5	Tomatoes	Slab mean	272	25	552	210	93	-	-
6	Tomatoes	Feed mean	264	30	432	207	83	-	-
		Slab mean	397	26	505	337	156	-	-
7	Cucumbers	Calculated	159	21	271	154	47	45	73
		Feed mean	148	67	315	203	37	60	67
		Slab mean	154	55	308	180	45	62	82
		Calculated	179	50	286	145	33	46	51

* when chlorides added to feed

For Grower 7 there were discrepancies between the concentrations calculated from fertilizer and water figures and the mean feed analysis, particularly for nitrate-N and calcium. Comparing feed and slab means showed that nitrate inputs were matched to crop uptake as the feed and slab levels were similar (148 and 154 mg/l, respectively). The same was true of potassium and calcium.

Table 5.7.2 (b) shows corresponding data for trace elements. These values are close to the ADAS recommended concentrations (Vaughan 1988, 1991; Ashdown, 1991). It is common for manganese to be depleted in the slabs compared to the input solution. Peppers required a greater concentration of boron than tomatoes and cucumbers to prevent deficiency. Of the trace elements, boron is the most likely to be of interest from a pollution point of view (see Section 4).

Table 5.72 Mean solution nutrient concentrations
(b) Trace elements

Grower No	Crop	Description	Fe mg/l	Mn mg/l	Cu mg/l	Zn mg/l	B mg/l	Mo mg/l
1	Tomatoes	Calculated	2.6	0.50	0.18	0.82	0.52	0.10
		Feed Mean	2.9	0.42	0.14	0.75	0.40	-
2	Peppers	Feed Mean	1.9	0.41	0.09	0.56	0.49	-
		Drain Mean	2.1	0.12	0.08	0.36	0.81	-
3	Cucumbers	Slab Mean	0.9	0.65	0.11	0.60	0.65	-
4	Tomatoes	Tank Mean	4.3	0.55	0.18	0.69	0.73	-
5	Tomatoes	Slab Mean	2.6	0.25	0.14	1.40	0.59	-
6	Tomatoes	Calculated	2.2	0.24	0.11	0.76	0.19	0.04
		Feed Mean	2.8	0.38	0.08	0.69	0.27	-
		Slab Mean	4.8	0.28	0.08	0.93	0.45	-
7	Cucumbers	Calculated	2.8	0.3	0.10	0.30	0.40	
		Feed Mean	1.9	0.54	0.18	0.31	0.36	-
		Slab Mean	2.3	0.52	0.22	0.44	0.39	-

5.8 Pesticides Applied to the Root Zone

Grower No 1 (rockwool tomatoes) applied no chemicals at all to the roots or stem bases. One of the cucumber growers (No 3) gave one application of Filex at the recommended rate (see Table 3.21). The other cucumber grower (No 7) used the maximum number of Filex applications allowed per crop. Grower 5 (rockwool tomatoes) made one application of Filex at less than the recommended rate; he also used Derosal WDG which is only cleared for NFT tomatoes. Grower 6 used Aaterra once at the recommended rate and Filex once, but at more than double the recommended rate. The pepper grower used one application of Filex after planting, at the recommended rate.

5.9 Crop Details

Crop details are shown in Table 5.9. For tomatoes, initial plant populations ranged from 2.30-2.47 plants/m² rising to 2.66-3.46 heads/m² after side shoots had been taken. Grower 2 had a low plant population for cucumbers (1.17 plants/m²); the 1.38 plants/m² of Grower 7 is typical. A pepper population of 3.40 plants/m² is higher than average (although few long-season crops are grown in the UK at present). Yields in excess of 50 kg/m² for tomatoes or 104 cues/m² are in the top league.

5.10 Glasshouse Environment

Table 7 summarises the data on glasshouse environment. Peppers and cucumbers were grown approximately 3-5°C warmer than tomatoes. All growers except No 7 had various strategies to control humidity. Higher pipe temperatures and air temperatures will increase transpiration by the crop and hence water use. Large differences in irrigation equipment and policy tended to swamp any patterns which might have emerged due to differences in glasshouse environment. Grower 7 had the lowest water use though running cucumber temperatures and with the highest yield of fruit.

Table 5.9 Crop Details

Grower No	Crop	Plant Population					Variety	Sowing date	Planting date	First pick	Plants stopped	Irrigation turned off	Plants cleared	Yield		
		Initial		Inc sideshoots		When taken								Marketable		Waste
		plants per m²	Plants per acre	heads per m²	heads per acre									kg/m²	tons/ acre	fruit kg/m²
1	Tomatoes	2.30	9,324	3.46	13,980	Feb/March	Calypso	28/10-2/11/91	16-17/12/91	10-2.92	14.9.92	31.10.92	Started 6.11.92	50.2	199	Not recorded
2	Peppers	3.40	13,759	6.80	27,518	At 11 leaves	Mazurka/ Ariane Elea Goldflame	15-22 10/90	19-26 11/90	6-7 3/91	End August 91	9-15 10/91	Last week Oct	18.8-21.7	75-86	Not recorded
3	Cucumbers	1.17	4,750	-	-	-	Corona	Mid -Jan 91	Mid-Feb 91	15-20 Mar	-	25.9.91	2.10.91	?	?	?
4	Tomatoes	2.35	9,500	3.21	13,000	w/c 17.2.92	Pronto	1.11.91	24-26 11.91	23.2.92	w/c 24.8.92	w/c 19.10.93	w/c 2.11.93	48.4	192	-
5	Tomatoes	2.47	10,000	3.29	13,333	mid-March	Spectra Calypso	7.11.90	4.12-early Jan	3rd wk Feb	end August	Mid-Oct	End October	39.0	155	2.5 (esti-mate)
6	Tomatoes	2.29	9,250	2.66	10,750	last week Feb	Liberto	8.11.91	4.12.91	10.3.92	20.9.92	1.11.92	15.11.92	42.6	169	1.7
7	Cucumbers	1.38	5,600	-	-	-	Rebella	9.11. 90	4. 12.90	Mid-Jan	Mid-Oct	Mid-Oct	Mid-Oct	118 cues /m²	226 (esti-mate)	?

Table 5.10 Glasshouse Environment

Grower No	Crop	Stage	Temp	Set points 0°C		Mean temp		Minimum pipe settings		Humidity Control
			Night	Day	Vent	Night	Day	Night	Day	Vent at 87%, 1-2% per % RH Heat + 4°C on min pipe temp from 83% but influence off above 25% vent
1	Tomatoes	3	16.5 + 1	18 + 2	23⇒21			45	45	
		4	17	18	19					
2	Peppers	1st month rest of season		23 19.5				40 (until May)	40-10 on light	40° pipe + 10° on humidity (day)
3	Cucumbers		17-19	22-23				30	50 with light reduction	Try to keep below 80-85% max
4	Tomatoes	December				24 hrs 17.9		40-50° C (on light)		Aim to keep RH below 85%
		January				18.1				
		February				18.0				
		March				19.4				
		April				20.2				
		May				22.3				
		June				22.4				
		July				20.8				
		August				19.9				
		September				18.2				
		October				17.8				
5	Tomatoes	Means March				17.2	20.9	40	40	Heat boost 82-85% 4°C per 1% RH
		April				17.0	19.8			Vent 85% RH 5% vent per 1% RH
		May				17.2	19.8			
		June				17.5	20.0			

Table 5.10 (contd)

Grower No	Crop	Stage	Temp	Set points 0°C		Mean temp		Minimum pipe settings		Humidity Control
			Night	Day	Vent	Night	Day	Night	Day	
6	Tomatoes	Up to 1st flower	18	20		19			55-40 light (to March)	Bring vent temp below heat set point Start control at 87% above 92% RH vent temp 0.2°C below set point
		Rest of season	16 + 1 following bright day	18 + 4		19			45-50 down to 25 on light (after March)	
7	Cucumbers	All season	20	21	22		40			No policy to control RH

6. NITRATE LOSS COMPARISONS

6. NITRATE LOSS COMPARISONS

No agricultural system can be 100% efficient in its use of nitrogen; nitrate leaching is a natural process and some loss each year is inevitable (Archer and Thompson, 1993). Agricultural land is the main source of nitrate in rural catchments. The amount of nitrate lost from a given area depends on the overall balance of agriculture and horticulture in the catchment. This means that the presence of some fields, intensive livestock units or glasshouses with high losses will not necessarily result in the overall water concentration exceeding 11.3 mg/l NO_3 - N. The quantity of nitrate lost from a farming system depends on the balance between inputs of nitrogen in the form of fertilisers and imported animals feeds, the quantity removed in crops and animal products from the farm and that lost by gaseous routes (ammonia volatilisation, denitrification) (Archer and Thompson, op. cit.).

Two particular practices can result in unnecessarily high leaching from any farming system:

- nitrogen use in excess of crop requirement.
- application of animal manures, sewage sludge or other organic wastes at excessive rates or inappropriate times.
- lack of crop cover during the Autumn and winter months.

5. CASE STUDIES

5.1 Methods

In order to gather data on actual nutrient losses seven growers were interviewed and detailed questionnaires completed (See Appendix I). The growers selected covered the major geographical areas of hydroponic production, three major edible crops and three production systems. Locations of nurseries have not been included to protect the growers' identities.

1. run-to-waste rockwool tomatoes.
2. recirculating rockwool peppers.
3. run-to-waste rockwool cucumbers.
4. NFT tomatoes.
5. run-to-waste rockwool tomatoes.
6. run-to-waste rockwool cucumbers.

Background details are shown in Table 5.1

Note: In this section and throughout the report run-off percentage has been calculated as follows:

$$\% \text{ run-off} = \frac{\text{drain volume}}{\text{total feed volume}} \times 100$$

The contribution of a nitrate source to pollution in a watercourse will depend on the *concentration* of the nitrate input, and the water *volume* in relation to other water inputs. In agriculture these are closely linked; the volume of water is determined mainly by rainfall, and to a lesser degree by the crop, which affects water use. The nitrate load is affected mainly by crop husbandry, and to a lesser degree by drainage volume. In the drier areas, and especially on the better bodied soils, there may be insufficient drainage to wash all the nitrate out of the soil profile over winter. However, in general, the greater the drainage volume, the smaller the concentration of nitrate. Also, drainage volumes from adjacent areas of land are normally fairly similar, so that contributions are related to the area occupied by a particular land use. Losses take place chiefly over winter, when fertiliser is not applied, so that total losses are limited to the quantity of nitrate held in the soil during the winter.

In horticulture, these compensating effects may not occur. Water volume is determined by irrigation practice; and concentration by feed applied. There is no intrinsic limit to the quantity of nitrate removed, and losses may take place throughout the year. There is a risk of large losses at times when the input from other agricultural sources is small.

Losses by leaching depend on soil type and rainfall. The lightest arable soils only retain about 150 mm total water per metre depth; so nitrate in these, and the shallow soils which are so extensive in the U.K., is much more easily leached than nitrate in deep clay or silt soils which may retain more than 400 mm of total water per metre (Lord, 1994; pers comm). The amount of rain which is in excess of evaporation and crop transpiration, and which therefore results in leaching, varies from about 150 mm in the east to more than 300 mm in some western and northern arable regions and to more than 1,000 mm in some grassland regions.

6.1 Estimates of Leaching Loss

Estimates of the nitrate that is actually leaching from soils are difficult to make; typical recent values are shown in Table 6.1.

Leaching losses in terms of kg N/ha/year can be converted to concentrations in the water passing down the soil profile if the annual rainfall is known. For example, in areas with

200mm excess winter rain (eg the Midlands) a loss of 23 kg N/ha would give an average concentration of 50 mg/l nitrate (11.3 mg/l NO_3 -N).

6.1.1 Cover Crops

Crop cover during winter is the main factor affecting how much of the nitrate present in soil in Autumn will be lost by leaching. An early-sown and well-established autumn crop can take up a substantial amount of N (e.g. 30-50 kg/ha) during autumn and early winter (Powlson and Davies, 1993). Sometimes it is not possible to grow a commercial crop during winter and high nitrate leaching often occurs as a result. For example, in the winter prior to growing potatoes, sugar beet or other crops that are not frost hardy, or in the autumn following a crop that is harvested late, such as potatoes. One option is to grow a winter cover crop with the aim of absorbing as much nitrate as possible during the autumn before winter leaching begins. Cover crops such as rye, winter barley, mustard or stubble turnips can sometimes absorb 50-90 kg N/ha (Powlson and Davies, op cit).

Table 6.1. Nitrate leaching loss from different crops, fertilised correctly and without use of manures

	kg N/ha/year
Unfertilized grass	0-10 (1)
Intensive dairying (grazed)	70-130 (2)
Winter cereals, Spring barley, Sugar beet	30
Beans and peas	60-70 (1)
Winter Oilseed Rape	75 (1)
Potatoes	100 (1)
Field Vegetables	100
HONS	80-360 (3)
Pine Forest	< 1

Refs.

(1) Sylvester-Bradley and Powlson, 1993.

(2) Lord, 1994; pers comm

(3) Harris and Burbridge, 1991.

6.2 Animal Manures

The risk of nitrate leaching from land which has received organic manures is considerable because they are commonly applied in amounts and at times which do not allow efficient uptake of N by crops (Pain and Smith, 1993). The main organic manures applied to agricultural land originate from housed livestock in the form of semi-liquid slurries or as more solid material containing straw, wood shavings, etc. such as farmyard manure (FYM) and poultry litter. Sewage sludge is applied to land as a means of disposal; 40% of the total is accounted for by spreading on farms (Pain and Smith, op. cit.). These manures are often applied to arable stubbles and grassland throughout the autumn and winter as and when convenient and soil conditions permit. The annual output of N by housed livestock in the U.K. has been estimated (Table 6.2). However, nationally the distribution is uneven and reflects variations in livestock density. By way of comparison, 500,000 t of N as animal manure, 15,000 t of N in sewage sludge and 1.5 m tonnes of N as chemical fertiliser are applied annually to agricultural land. Between 10 and 70% of the nitrogen in these manures is in a readily available form which is at risk of leaching in the winter of application (Lord, 1994 pers comm).

Table 6.2. **Estimated annual output of N by housed livestock in the U.K.**

	N (tonnes)
Cattle	320,000
Pigs	80,000
Poultry	110,000
Total	510,000

(after Pain and Smith, 1993).

Nitrate losses after cattle slurry applications to grassland are relatively low but more significant losses are likely from applications to arable land. The most convenient time for applying slurries and manures is often on cereal stubble before cultivating for the next crop. This maximises the risk of leaching as work at ADAS Gleadthorpe has shown. After poultry manures had been applied in October (on bare ground), all of the available nitrogen was lost by leaching. Losses from a November application were over 50%, but from a mid-December application losses were below 10%. (Unwin et al, 1990).

If manures are correctly applied, they should not lead to much extra leaching; However, fields which have been used for disposal of manures for many years at high rates may have annual losses in excess of 900 kg N/ha.

These experiments also showed that losses from FYM were much smaller than from slurries or poultry manures. The nitrogen in such straw-based manures is known to be released more slowly. Nevertheless, it is generally true that addition of organic material to soils eventually increases the potential for nitrate leaching.

There has been a considerable amount of work on nitrate losses associated with manure applications. For a review including experimental results see Pain and Smith (1993).

Currently, restricting the time and rate of application is the simplest and most reliable way of reducing the risk of nitrate leaching from organic manures. Application rates should be adjusted so that the supply of plant nutrients does not exceed crop requirements. The Code of Good Agricultural Practice for the Protection of Water (MAFF, 1991) recommends a maximum application rate of 250 kg N/ha although lower limits may be appropriate in Nitrate Vulnerable Zones. The new EC Nitrate Directive (see Section 2) will ultimately limit application rates for organic manures to 170 kg N/ha within designated Nitrate Vulnerable Zones unless an objective case for higher rates can be sustained (Pain and Smith, op. cit.).

6.3 Grassland

The current maximum recommended rates for dairy systems range from 300 to 380 kg N/ha for grazed and from 340 to 420 kg N/ha for cut swards; 11% of intensively managed grassland in the U.K. receives more than 300 kg N/ha. Where grass is cut, even very high fertiliser rates are unlikely to result in substantial nitrate leaching if applications are made which closely match the crop's needs. However, once grazing animals are introduced, grassland may become a significant source of nitrate leaching and of gaseous N losses (Jarvis and Dampney, 1993). Very large proportions of the N consumed in the herbage are excreted and recycled back to pastures. Increasing the inputs of fertiliser N increases ingestion by the ruminant and the total amount of N excreted. This in turn increases the leaching losses (Table 6.3).

Table 6.3. **The influence of nitrogen input level and drainage on nitrate leaching from grazed permanent grassland.**

	kg N/ha/year
200 kg fertiliser N/ha	
undrained	15
drained	60
400 kg fertiliser N/ha	
undrained	75
drained	195

(after Jarvis and Dampney, 1993).

Because of the extent of losses from grazed systems, the concentration of nitrate in leachate is often high, especially under long term swards; values ranging from 34 to 90 mg/l N have been measures for conventionally grazed swards. (Jarvis and Dampney, op cit).

6.4 Container-grown hardy ornamental nursery stock

Only a minority of container grown nursery stock is grown under glass or polythene where water application can be (relatively) carefully controlled. The majority stands outside receiving rainfall and also irrigation in dry periods. Container HONS production in the UK has increased rapidly over the past 20 years. MAFF Census Data gave the area in 1992 at 962 ha compared to 353 ha in 1982. The very rapid expansion of the industry during the 1980's has not been sustained into the 1990's and further expansion is likely to be more gradual (Rowell, 1993, pers comm). An estimated 20% of the area consists of capillary-type sand beds where leaching should be substantially reduced (Harris, 1991).

The majority of container HONS is grown in peat-based growing media, with an open structure (air-filled porosity 13-15% +), and stood out on gravel beds with overhead irrigation. These factors, coupled with the use of controlled-release fertilisers (CRF) at high rates (equivalent to 400-1,000 kg N/ha; Richardson, 1991 pers comm) lead to the potential for severe leaching. Furthermore, acidification of "hard" water with nitric acid is on the increase and this adds nitrogen to the applied water. Clearly, nitrogen added in this way to water which falls on the standing-out ground will add to the leaching losses.

An experiment was set up at HRI Efford in Spring 1990 to measure levels of nitrate, phosphate and pesticides leaching from a typical container HONS production system by monitoring regularly the drainage water from an area of gravel beds. This was a joint project, funded by MAFF, involving HRI, FDEU, ADAS Soil Science and the Pesticide Analysis Group of the Central Science Laboratory.

All the leachate was collected from drained gravel beds which were lined with polythene to prevent seepage to ground water. There were four treatments:

1. Standard rate CRF and standard irrigation (designed to meet crop requirements).

2. Standard rate CRF and high irrigation (significantly above crop requirements to simulate a wet season).

3. Low rate CRF plus supplementary liquid feeds and standard irrigation.

4. Low rate CRF plus supplementary feed and high irrigation.

Standard rate	8 kg/m³ Osmocote Plus 12-14 month (15% N).
Low rate	4 kg/m³.

This is equivalent to 512 kg N/ha at the low rate and 1024 kg N/ha at the standard rate (excluding N in background water, acid and liquid feed).

Rainfall over the experimental periods in 1990 and 1991 represented just over 60% of the long-term average in the period July to November inclusive. Rainfall in 1992 was much higher than that experienced in 1990 or 1991, representing 177-185% of the long-term average (July to November), inclusive. Total leaching of nitrate was calculated from run-off and concentration data. Results for the three seasons that the trial ran are given in Table 6.4. Average losses over a season for the standard rate CRF and standard irrigation treatment on a gravel bed ranged from 68-127 kg N/ha. Average nitrate-N concentrations in the run-off for the same treatment ranged from 69 to 207 mg/l NO_3-N.

In 1990 the growing system in the trial represented the "worst-case" scenario with overhead irrigation, open-structured growing media and a drained gravel bed. In 1991, three of the beds were converted to capillary-type sand beds to see what effect this had on leaching.

Table 6.4 Nitrate N concentrations and total N losses from the Efford leaching from container-grown HONS trial

mean values and ranges

	NO_3-N mg/l	kg N/ha
1990		
Treatment 1 (1)	69	127
All treatments range (2)	20-140	78-358
1991		
Treatment 1 gravel (1)	207	114
Treatment 3 Sand (1)	177	101
1992		
Treatment 1 Gravel (1)	66	68
Treatment 1 Sand (1)	65	74
All treatments range (1)	6.5-132	37-92

(after Harris and Burbridge, 1991
Harris and Burbridge, 1992
Harris and Pepper, 1993)

In 1992 where the standard treatment could be compared on sand and gravel beds, total N losses were slightly higher from the sand beds than from gravel, although nitrate concentrations were similar.

This trial does not completely reflect reality, as all the run-off was captured and recorded. Losses are therefore calculated per ha of bed, ignoring any pathways. Irrigation (with or without acid and feed) and rainfall falling on paths on a commercial nursery would affect overall N losses. Also, drainage of the leachate through the soil would be expected to have a mitigating effect on phosphate and some of the agrochemicals, but probably less effect on the nitrate on a free-draining sandy soil.

6.5 Assessing losses of nitrate from whole catchments

In order to estimate present and future leaching losses from whole catchments models have been developed. By using these models it is possible to estimate the amount of nitrate that will be leached in different situations, to identify the most effective and cost-effective ways of reducing nitrate leaching and to estimate the timescale for changes to be reflected in abstracted water (Lord et. al. 1993).

The factors which affect N losses include previous crops, soil type, manure and nitrogen inputs as well as yield. The concentration of leaching N is also affected by drainage volume. In streams, N concentrations reflect recent losses. In ground waters, concentrations at the borehole reflect losses in previous decades since it takes many years for water to pass through the rock to the borehole (see Section 3.15).

Estimates from the models of nitrate leaching over the last 20 years indicate that in several NSA's nitrate concentrations leaving the soil zone have been, and still are, well above the 11.3 mg/l NO_3-N Drinking Water Directive limit. (Lord et al, 1993). However, nitrate concentrations in the water abstracted from the boreholes in these areas, which have been monitored over the same period, are below 11.3 mg/l on average.

Losses of nitrate from hydroponic crops are compared with data from this section and discussed in Section 9.

7. UK SITUATION COMPARED TO HOLLAND

7. UK SITUATION COMPARED TO HOLLAND

The EC Nitrate Directive (see Section 2) applies to all member states of the European Community. Early estimates suggested that 2 million ha of the UK might need to be included in Vulnerable Zones. This is equivalent to 20% of the agricultural land of England and Wales. Some member states, eg Denmark and the Netherlands, expect to have to designate the whole of their territories.

The agriculture and horticulture sector is very important in Holland. In 1988, it accounted for 12.5% of the national income, provided about 475,000 jobs and made a major contribution to the Netherlands balance of trade (Ministry of Agriculture, Nature Management and Fisheries, 1990). The Dutch glasshouse industry is four times the area of ours, in an area one quarter the size of England and Wales. In addition, the glass is concentrated in only a few areas (see Fig 7.1). In terms of area, the Westland and De Kring represent around 1% of the Netherlands, but in these districts alone growers use one-sixth of the total quantity of crop protection chemicals applied (Oosterhout, 1991). The area devoted to horticultural crops in England and Wales is now only 5% of the cultivated area (although this represents 32% of the output value, see Table 7.1).

Table 7.1 Importance of the Horticultural Industry to the Economy of the UK

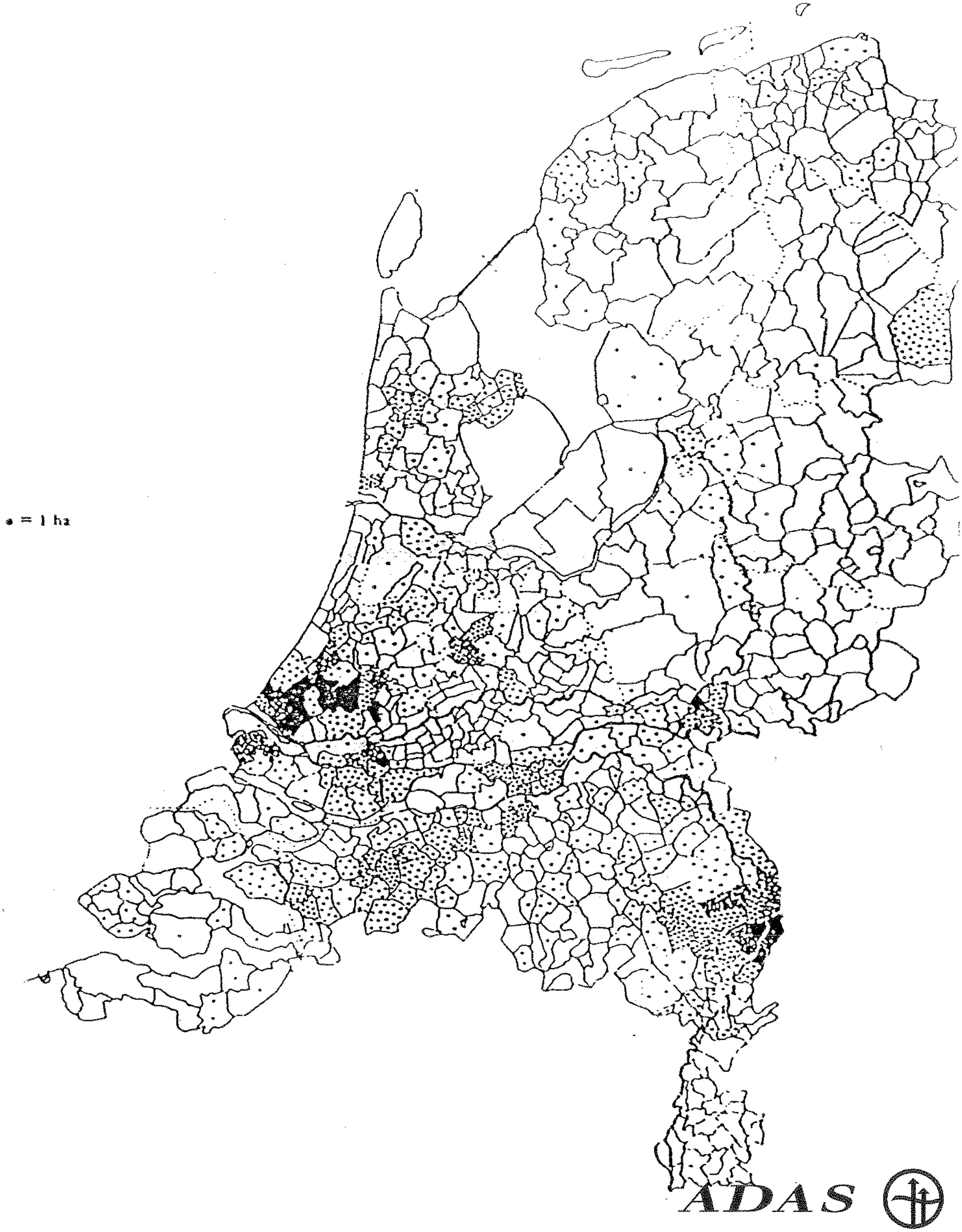
	Area ,000 Ha	**Value of Output £ million**
Cereals	3485	2226
Other Arable	1110	705
Potatoes	180	442
Outdoor Vegetables	197	618
Protected Vegetables	2.8	323
Other Horticulture	49.7	636

Source: Agriculture Statistics MAFF 1993

The environmental action plan for horticulture in the Netherlands assumes that by the year 2000 glasshouse horticulture must have achieved a totally or almost totally closed operating system with no emissions. Anything that is allowed to escape into the environment must meet strict standards. The main aims are set out in the Structuurnota Landbouw (Agriculture Structure Memorandum), the Meerjarenplan gewasbescherming (long-term programme for plant protection)

Fig 7. Distribution of glasshouse vegetable nurseries in Holland

Total area of holdings: 4432 ha
Total no. of holdings: 4395



ADAS

and the Convenant between Delfland and the board of Agriculture. There is also the following legislation:

Soil Protection Act
Air Pollution Act
Surface Water Pollution Act (Wet Verontreiniging Oppervlaketewater or WVO)
Soil Water Act

The following results are meant to be achieved by the year 2000:

All crops

- cultivation in virtually closed cultivation systems
- reduction of emissions into the air, soil and water

Vegetable crops

- 64% reduction in consumption of crop protection products*

Flower crops

- 65% reduction in consumption of crop protection products*

All nurseries

- licence under the Law on Surface Water Pollution (WVO).

*relative to the average during the period 1984-1988.

These aims have been formalised in the Multi-Year Crop Protection Plan (MYCPP).

This sets out three strategies which apply to all sectors. In practice, a high level of investment will be inevitable.

1. To reduce current dependency on chemical pesticides by encouraging the adoption of integrated production systems, the use of pest and disease resistant varieties and wider crop rotation.

2. To reduce the use of pesticides by non-chemical means of weed control, the adoption biological control of pests and diseases and the reduction in use of soil sterilants.

3. The reduction of pesticide emissions into the atmosphere or the environment in general especially by the glasshouse and mushroom industries by developing a "closed re-circulating hydroponic system".

   The key points are:

   - 80% of glasshouse vegetable production to be grown in closed circulation hydroponic systems by 1995; this will be increased to 100% of all crops by the year 2000.

   - pesticides have to be reduced by 35% by 1995 and at least 50% by the year 2000.

All production sectors must contribute to the reduction. In 1988 the glasshouse vegetable sector in Holland used 470 tonnes of active ingredient. In England and Wales the corresponding figure for edible glasshouse crops was 149 tonnes in 1991.

However hydroponic tomato and cucumber crops both in the UK and Holland are commonly grown using integrated pest management. This is particularly true of tomatoes, where very few insecticide and acaricide sprays are used although some fungicides are required.

There is evidence that the Dutch intend to enforce the plan with a number of obligatory measures which may be tightened up if the 1995 and 2000 date targets are not met. Relatively few Dutch growers use re-circulating hydroponic systems at present (c.5%). The majority of those who are currently using run-to-waste systems face substantial investment in order to re-circulate the nutrient solution and to adopt some form of sterilisation. Recent returns have been no better in Holland than in the UK and growers are waiting until they are forced to re-circulate or for financial help in the form of grants to be introduced. The Dutch government has already allocated £300,000 to set up a 15 MYCPP offices to advise growers on how to implement the MYCPP.

Additional funds have been allocated for R&D, for example at PTG Naaldwijk. Other areas under scrutiny include waste products such as rockwool, polythene, crop waste and assimilation lighting. Records must be kept on consumption of fertilisers and plant protection chemicals. Surplus plant protection products are to be processed at treatment centres so that they do not end up in the environment or the sewage system. Work is also being done on the construction and equipment of glasshouses to reduce environmental pollution. For instance, new galvanised steel gutters must be coated in plastic to prevent zinc leaching into the soil. Eventually the aim is to issue a mark of approval for glasshouses which prevent water and soil pollution.

In 1991 an agreement was signed between the Delfland Canal Board and the Regional Council of the Lanbouwschap (Agriculture Board). In this agreement, provisions were made for a sweeping reduction in water pollution caused by surplus crop protection chemicals and nutrients. Overall provisions have been made for the period up to 30 September 1994 with regard to percentage reductions in the whole range of crop protection chemicals which are detected in the water.

The agreement specifies two percentages which are the agreed levels for the reduction in the emission of crop-protection chemicals. The Canal Board has since 1987 been monitoring the concentrations of various crop-protection chemicals in the surface water. For these chemicals, the concentration is required by the 30 September 1994 to be 92% lower than the level measured in 1987.

For those chemicals which cannot take 1987 as their reference point because their concentrations were not yet being recorded at that stage, the reference point will be 1991. By 1994, the emission of these chemicals must be 80% below the level recorded in the 1991 growing season.

There are substantial differences between crop-protection chemicals in terms of their toxicity and concentration in the surface water. The concentration of a number of chemicals is already below the safe limit, or is certain to drop to that level during the term of the agreement (Oosterhout, 1991). Other chemicals are way in excess of the "safe value". Parathion, for example, is more than 200 times over the agreed limit, and dichlorvos 1200 times (Oosterhout, op cit). In spite of complying with the provisions contained in the agreement, it is probable that the concentrations of some chemicals will not drop far enough by the end of the agreed period. Other water and canal boards are carrying out similar monitoring in other areas.

For the final phase, maximum standards are being imposed by the government. It will then be necessary for the surface water to comply with what is called General Environment Quality. This is a standard based on the criteria of normal flora and fauna development. For chemicals which are expected to exceed the standard at the end of 1994, supplementary measures will be necessary. A survey of the ditches in the area around the glasshouse area of Delfland showed a severely disturbed ecological balance. The only surviving organisms were mosquito larvae, worms and certain snails. The water in question was classified as "ecologically dead" by the Ministry for Housing, Regional Development and the Environment. The dire state of the Westland surface water is not, according to the Canal Board, irreversible, but a lot of time and care will be needed to ensure its recovery (Oosterhout, 1991).

As in the UK, growers need a licence to discharge into surface water under the WVO. The system is being introduced gradually: first new businesses, then nurseries which are being renovated, followed by existing substrate nurseries and, finally, crops grown in the ground. It is envisaged that all growers will have a licence by 1995 (Koop, 1991). Discharges to the ground are also covered (theoretically), though in practice the implications are still being worked out.

Licences are also required for abstracting water though the amount of water which can be extracted without a licence varies from province to province.

Despite the fact that much of Holland is below sea level and has a very high water table good quality water is not easily available. Pollution has rendered some ground, surface and tap water virtually useless for re-circulation. In areas where that is the case, rain water is collected in storage tanks either above or below the ground. Tap water in many areas, especially the Westland, is unsuitable for re-circulation because of excessive amounts of sodium and chloride.

With many growers in Holland facing financial difficulties due to poor returns there is limited scope for investment to reduce environmental problems. Costings for re-circulating systems in Holland have sometimes been based on depreciation of seven to ten years for permanent systems. Due to rapid developments and uncertainties perhaps five years would be more realistic. Alternatively low cost systems might be considered, without sterilisation.

One study using computer modelling techniques suggests that non-disinfection might be acceptable providing infected plants are detected and removed (Hummel & Trip, 1991). However, banks providing finance may not take the same view of this disease risk.

8. ALTERNATIVES TO RECIRCULATION

8. ALTERNATIVES TO RECIRCULATION

8.1 Use of Waste Nutrient Solution as Liquid Fertiliser for Outdoor Crops

Waste nutrient solution from rockwool crops typically contains 125-250 mg/l N and 25-40 mg/l P; run-off from tomato crops December to March could contain much higher levels of nitrogen: up to 550 mg/l N. The use of chlorides for tomatoes (see Section 8.2) is reducing nitrate levels with some growers now achieving 200 mg/l or less early season and 125 mg/l main season or even lower. If these nutrient levels are compared for example to those found in liquid nitrogen fertilisers or foliar phosphate applied to potatoes, it can be seen that rockwool run-off is far more dilute (Table 8.11).

Obviously, rockwool run-off is far too dilute to be worth transporting any distance. It is best viewed as potential irrigation water, with the nutrient content taken into account as a bonus.

The total area irrigated varies from approximately 0.75 to 1.5% of the total cropped area of over 10 million ha in England and Wales. The most important crops irrigated are potatoes, sugar beet and vegetables; in 1992 potatoes made up half of the area irrigated and vegetables c.20% (Stansfield 1993).

Table 8.11 Comparison of nutrient content of rockwool run-off, liquid fertilisers and foliar phosphate solutions for potatoes

	mg/l	
	N	**P**
Rockwool run-off (main season)	125-250	25-40
Liquid nitrogen fertilizer (arable crops)	190,000-370,000	
Foliar phosphate solution (potatoes)		13,500

Irrigation water requirements are quite small, compared to industrial and domestic usage (see Table 3.17).

However, there are marked differences between different parts of the country with the highest demand for outdoor irrigation in the East where it can represent nearly half the daily water requirements in drought periods (Stansfield, op cit).

Irrigation is generally required from April to September with most applied in June, July and August. It is this high demand in a short period when effective rainfall is lowest and other uses for water are at their maximum that creates problems in water resource management. June to August inclusive is also the period of maximum water use for rockwool crops and therefore of maximum run-off (if the percentage run-off is relatively constant during the main season). This means that there is the potential for some growers to use the run-off to irrigate outdoor crops. Whether this is feasible will depend on the close proximity of suitable crops. Any form of transport or storage will be expensive, the cheapest option will be to supply adjacent fields by pipeline connected to an automatic travelling irrigator (eg Briggs). There has been a trend in recent years for farmers to increase the amount of water taken from boreholes, or to construct reservoirs. This is because surface water sources are subject to abstraction bans in drought periods. In the driest year up to 240 million cubic metres of water are needed. Supplies cannot meet this demand and much of the requirement will need to be met by storage. Demands from consumers (or supermarket buyers) for precise quality produce, require farmers and growers to have a regular, uninterrupted supply of irrigation water.

Maximum summer soil moisture deficits (SMD's) are used to define areas where irrigation demand is greatest. The higher the SMD value, the greater the irrigation demand. Outdoor irrigation is a possibility for rockwool growers on the South Coast, the whole of Eastern England including Kent and Lea Valley plus the Vale of Evesham. It is less likely to be an option for growers in north Humberside and highly unlikely for Lancashire growers.

Suitable crops

Main crop potatoes have a high demand for irrigation, especially where a high quality skin finish and required as regular irrigation in dry weather is used to reduce the incidence of common scab. Vegetables, including salads, are another possibility. Intensively managed grass is an attractive option as it has a large nitrogen requirement. The current maximum recommended rates for dairy systems range from 300-350 kg N/ha for grazed and 340-420 kg N/ha for cut swards. Unfortunately, the main dairy regions are situated in areas of high rainfall, away from most glasshouses.

Taking a typical water use of about 1500 l/m^2 the run-off during the period April-September could be approximately 600 l/m^2. If this contained only 125 mg/l N, this is equivalent to 750 kg N/ha. Therefore the run-off from one ha of tomatoes would supply the nitrogen requirement of 1.8-2.2 ha of intensively cut grass (for silage). Run-off of 600 l/m^2 is equivalent to 600mm irrigation; the maximum planned irrigation requirement for grass in the driest areas on the droughtiest soil is only 250mm.

One tenet of the Code of Good Agricultural Practice for the Protection of Water (MAFF, 1991) is that the "available" nitrogen in organic wastes applied to land should not exceed the crop's requirement (para 27). All the nitrogen in rockwool run-off is available. Table 8.12 gives the areas of crops that would be required to meet this requirement of the Code. Obviously, if the amount of run-off could be reduced, then less crop area would be required.

Soft fruit is a possible candidate as the area down to fertigation with trickle application is increasing. However, strawberries only require about 40-80 kg N/ha in this form (HDC Project SF 18/33).

Table 8.12 Crop areas required to dispose of the run-off from 1 ha glass (April-September) such that the crop nitrogen requirement is not exceeded (Soil N index O)

	ha
Intensively managed grassland - grazed	2.0-2.5
- cut	1.8-2.2
Cereals	2.7-6.0
Main crop potatoes	3.5-5.8
Sugar beet	6.0-7.5
Top orchard fruit	7.5-25.0
Soft fruit	5.4-15.0
Vegetables	
- Leeks and onions	8.3-25.0
- Carrots	12.5
- Celery	6.0-15.0
- Lettuce	3.8-6.0
- Cauliflower	2.7-3.8
- Brussel sprouts	2.5-3.8
- Cabbage	3.0-1.9

8.2 Reducing the Nitrate Content of Feeds

The amount of nitrogen lost from a run-to-waste hydroponic solution depends upon:

(a) the volume of run-off

Therefore, one of the means by which nitrogen loss may be reduced is to substitute chloride for some of the nitrogen in the feed solution.

As long ago as 1980, Attenburrow and Waller found about a 10% reduction in the yield of tomatoes grown in NFT when 8.5-14.4mM sodium chloride was allowed to accumulate in the recirculating solution as compared with the yield obtained with the same levels of nutrients in de-ionised water. However, they did not establish the optimum level of sodium chloride for tomatoes.

Even earlier studies in solution culture showed that the addition of moderate amounts of sodium chloride to the basic nutrient solution could promote growth (for a summary of early work see Adams, 1988).

In 1988 the ADAS recommended maximum level for both sodium and chloride in the applied rockwool solution was 400 mg/l (Vaughan, 1988). Adams, working at Littlehampton, designed an experiment to study the responses of tomato to a wide range of salinity levels (Adams, *op. cit*).

Seed of cv. Marathon was sown in late February in two consecutive years. Each plot consisted of a separate NFT system containing 150 l of solution and fifteen plants (2.37 per m^2; 9,597 per acre). Different sodium levels were obtained by adding sodium chloride to a basic nutrient solution. In 1985, three levels of sodium (*c.*500, 1,000 and 1500 mg/l) were compared with a control in which sodium from the water supply (14 mg/l) was allowed to accumulate to an average concentration of 85 mg/l. In 1986, four levels of sodium (*c.*500, 850, 1,200 and 1,560 mg/l) were compared with a control that was maintained at 150 mg/l Na. Conductivity increased with increasing sodium chloride concentration.

Leaves became progessively darker as the concentration of sodium chloride in the solution increased; leaf sodium content also increased with the level of applied sodium. Calcium deficiency symptoms on the leaves occurred in May and were most marked on the control plants, becoming less severe as the level of sodium increased.

The calcium content of the leaves increased from 1.78% at 150 mg/l Na to 2.4% at 1560 mg/l Na. The uptake of magnesium by the whole plant also increased with increasing salinity, though less consistently. No figures are given for the magnesium content of the leaves.

None of the plants wilted in very hot weather, even at the highest rate of sodium, and showed no signs of toxicity.

In both years, the yield during the first four weeks of harvesting was depressed progressively as the level of applied sodium increased. However, at 500 mg/l Na, the yield was only reduced during two of the first four weeks of harvest.

The highest total yields were achieved in both years by maintaining 500 mg/l Na in the recirculating solutions, which gave average EC values of 5.5 and 4.6 mS cm^{-1}.

Although the nutrient solution contained 339 mg/l K, the proportion of Class I fruit was always improved by increasing the level of sodium applied. The dry matter content of the fruit increased progressively with the sodium content of the nutrient solutions. A parallel response was found for the sugar content, which accounts for about 50% of the dry matter in the fruit (Adams, op cit). The titratable acidity also increased with sodium level.

Blossom-end rot affected very few fruit in either year, even at the highest level of sodium, only occurring during the first four weeks of harvest. The calcium content of the fruit declined as the concentration of sodium in the nutrient solution increased; this decline was most marked in the distal portion (blossom-end) as compared with the rest of the fruit. In a later experiment (Adams 1991) there were higher calcium concentrations in fruit and less blossom-end rot where conductivity was increased with sodium chloride than with extra major nutrients. The sodium content of the fruit increased as solution Na concentration increased whereas the potassium content was unaffected.

There were also effects of salinity on water and nutrient uptake: plants grown at intermediate sodium levels (500 and 850 mg/l) used 7% more water than the control.

The amount of nitric acid required to neutralise incoming water was directly related to the quantity of water needed to maintain the volume in each system. However, the *proportion* of the acid required to neutralize alkalinity arising from biological activity in the root zone (ie roots plus microflora) increased with the salinity of the nutrient solution.

The addition of 500 mg/l Na as sodium chloride to the basic nutrient solution increased the total yield of fruit by 2 and 6% in 1985 and 1986 despite average EC values for the whole season of 5.5 and 4.6 mS cm-^{1} respectively.

Adams concluded that the stimulation in growth and yield appeared to be due to salinity rather than to sodium chloride *per se*.

Marks (1991) compared a standard main season feed at 2.5 mS cm-^{1} with a base feed of 2.0 mS cm-^{1} plus sodium chloride to raise the EC to 2.6 mS cm-^{1} . Where sodium chloride was added the magnesium concentration was increased in the leaves despite lower levels in both the applied feed and the root environment (Table 8.21). Magnesium deficiency occurs quite commonly in early tomato crops during March and April when there is a heavy fruit load and root growth is weakened. Any improvement in magnesiumm uptake as a result of using sodium chloride is an important advantage.

Table 8.21 Effects of adding sodium chloride on nutrient concentrations

	Standard Feed				+ Sodium chloride			
	Applied feed (mg/litre)	Root environment (mg/litre)	Leaves (%)	Fruit (%)	Applied feed (mg/litre)	Root environment (mg litre)	Leaves (%)	Fruit (%)
Potassium (K)	478	622	4.2	4.8	303	289	3.8	4.7
Magnesium (Mg)	54	85	0.46	0.15	47	66	0.52	0.15
Sodium (Na)	30	58	0.10	0.06	161	318	0.34	0.13
Chloride (C1)	48	45	0.32	0.43	249	470	0.74	0.70

Standard feed: balanced nutrient solution applied at 2,500µS conductivity

+ Sodium chloride: balanced nutrient solution applied at 2,000µS plus sodium chloride to raise conductivity to 2,500µS

For both treatments the conductivity of the root environment was maintained at 3,000µS

Marks (1991) also carried out taste panel assessments. In 1988 most panel members could identify, and preferred, tomatoes grown with added sodium chloride. Unfortunately, the next year taste panels showed an equal preference for tomatoes grown with and without sodium chloride. Marks considers this difference may be related to different weather conditions in the two years. The summer of 1988 was comparatively dull and at the time of the taste panel assessments the fruit contained much lower sugar levels and was slightly acid. This suggests that the saltiness component may be more readily identified if the fruit has low sugar levels and poor taste characteristics (Marks, op. cit).

A further aspect to emerge from this study was that a minority of taste panel members were very sensitive to saltiness and could consistently identify tomatoes grown with sodiun chloride. However, they disliked the greater saltiness and strongly preferred tomatoes grown without sodium chloride. This suggests that a small proportion of consumers would not welcome saltier tomatoes.

In the Netherlands, the greenhouses are situated mainly in the western part of the country. Surface water from the canals and ditches in this region is used for irrigation of greenhouse crops. The quality of this water is strongly affected by the quality of the water in the River Rhine. The salt content of the Rhine has greatly increased over recent decades, mainly caused by industrial developments in Germany and France (Sonneveld, 1988). In order to obtain estimates of yield reductions of greenhouse crops caused by saline irrigation, water experiments began in the 1960's at PTG Naaldwijk for soil grown crops. Some experiments have also been carried out for soilless culture (Sonneveld and Van der Burg, 1991). Tomato, cucumber and pepper were grown in recirculating hydroponic systems. The EC of the nutrient solution was maintained at values of 2.5, 3.7 or 5.2 mS cm^{-1} (25°C) by addition of either nutrients only or a combination of sodium chloride and nutrients. The concentrations of sodium and chloride were 115, 228 and 575 mg/l for sodium and 178, 444 and 888 for chloride. One pepper crop and two tomato and cucumber crops were grown. The growing periods and cultivar used are listed in Table 8.2

Table 8.2 Growing periods of the crops after planting out and cultivars used

Crop	Growing Period	Cultivar
Tomato (1)	Jul 1985-Nov 1985	Estafette
Tomato (2)	Jan 1986-Sep 1986	Turbo
Sweet pepper	Dec 1986-Oct 1987	Plutona
Cucumber (1)	Jan 1988-May 1988	Ventura
Cucumber (2)	Aug 1988-Oct 1988	Corona

(after Sonneveld and Van der Burg, 1991)

The solutions were analysed weekly for sodium and chloride, and the uptakes of these elements were calculated as mmol per litre of water absorbed, from the amounts of Na Cl and water removed from the system.

The marketable fruit yields were reduced at the two higher EC values (3.7 and 5.2 mS cm^{-1}) in all crops (Table 8.23). With tomato (Crop 2) and sweet pepper, the yield reduction was brought about by a lower fruit number as well as a lower fruit weight. With cucumber the lower fruit number was a dominant factor in Crop 1 only. High sodium chloride did not specifically affect fruit yield of tomato. With sweet pepper and cucumber a tendency towards a specific effect was found, but this was significant only for the high EC value in the second cucumber crop.

Table 8.23. Yields of marketable fruits given as number and kg m^{-2}. Average fruit weights (FrW) expressed in g.

Treatment			Tomato Crop 1			Tomato Crop 2		
EC (mS cm^{-1})	Na (mg/l)	Cl	Number	kg m^{-2}	FrW	Number	kg m^{-2}	FrW
2.5	115	178	79	7.2	91	303	24.7	82
3.7	115	178	82	7.0	85	296	23.1	78
3.7	288	144	81	7.0	87	298	23.4	79
5.2	115	178	81	6.7	83	276	20.4	74
5.2	575	888	86	6.8	79	279	20.8	75
LSD (0.05)			ns	0.5	6	21	1.9	4
			Sweet Pepper					
2.5	115	178	96	14.0	147			
3.7	115	178	96	13.5	141			
3.7	288	444	90	12.5	139			
5.2	115	178	85	11.7	138			
5.2	575	888	80	11.1	139			
LSD (0.05)			9	1.3	4			
			Cucumber Crop 1			Cucumber Crop 2		
2.5	115	178	50	24.7	498	20	10.2	523
3.7	115	178	47	23.0	494	20	10.0	513
3.7	288	444	45	22.3	496	20	10.2	510
5.2	115	178	43	20.7	486	20	9.9	506
5.2	575	888	41	20.3	495	17	8.6	512
LSD (0.05)			3	1.5	ns	2	1.0	ns

(after Sonneveld and Van der Burg, 1991)

From the data in Table 8.23, salinity threshold values (t) and salinity yield decrease (SYD) values were calculated. The salinity threshold is the value above which yield begins to decline as conductivity increases; the salinity yield decrease is the rate at which the yield declines as conductivity increases beyond the threshold value.

The equations used to calculate t and SYD are given below:

$$t = 3.7\ (\mathrm{dS\ m^{-1}}) - \frac{(Y_{(2.5)}) - Y_{(3.7)}\ (5.2\text{-}3.7)}{Y_{(3.7)} - Y_{(5.2)}}\ (\mathrm{dS\ m^{-1}})$$

$$SYD = \frac{(Y_{(5.2)} - Y_{(3.7)}) \times 100\ \%}{Y_{2.5}\ (5.2\text{-}3.7)\ (\mathrm{dS\ m^{-1}})}$$

where Y(x) is the fruit yield at the EC value indicated by x.

In the equations given, it is assumed that yield reductions above the salinity threshold are linear (Maas and Hoffman, 1977) and that the salinity threshold is below a value of 3.7mS cm^{-1}; this was confirmed by the data. Results of the calculations are given in Table 8.24.

Table 8.24. Salinity threshold values (t) and salinity yield decrease values (SYD) of kg marketable fruit calculated from the data of Table 3

Experiment	t (mS cm^{-1})	SYD (% per mS cm^{-1})
Tomato crop 1 July-Nov	2.5	2.3
crop 2 Jan-Sep	2.9	7.2
Sweet pepper Dec-Oct	2.8	7.6
Cucumber crop 1 Jan-May	2.3	5.8
crop 2 Aug-Oct	3.5	5.6

after Sonneveld and Van der Burg (1991)

Fruit quality was also affected: blossom-end rot in tomato and sweet pepper increased with increasing EC values. In sweet pepper the disorder was specifically associated with high NaCl. Increasing sodium chloride concentrations lower the ion activity ratio between calcium and the sum of the other cations, and may result in a lower calcium absorption, thereby inducing blossom-end rot (Bennet and Adams, 1970; Shear, 1975). Sweet pepper is very prone to blossom-end rot and so with increasing sodium concentrations in the root zone an increase in the calcium concentration may be necessary for this crop in order to maintain an adequate ion activity ratio. Apart from blossom-end rot, the external fruit quality was generally improved by increasing EC values, in terms of longer shelf life (tomato and cucumber) higher colour index (cucumber) and decrease in russetting (tomato) and green spot (pepper). The internal quality of tomato improved in terms of higher acid content and refraction with increasing EC value. There was no consistent effect of EC on the Vitamin C content of sweet pepper.

The differences in water uptake of the crops between treatments was marginal. The absorption of sodium and chloride by the crops was strongly affected by the concentration of the elements in the root environment. Chloride was nearly always absorbed in greater quantities than sodium. The sodium absorption of sweet pepper was generally lower than that of other crops and seemed to be noticeable only during the first few months of growing. Later on, there was hardly any absorption of sodium by this crop resulting in very low leaf and fruit concentrations (eg 3 mmol per kg dry matter; 0.007% sodium in pepper leaves, regardless of the sodium chloride concentration in the root zone).

According to Sonneveld, maximum yield of rockwool grown crops can be obtained with nutrient concentrations resulting in an EC value of 1.5 mS cm^{-1} (Sonneveld 1988b). This means that if the normal EC value of 3.0 mS cm^{-1} (25°C) used in Holland is maintained in the root environment, the difference between 1.5 and 3.0 mS cm^{-1} can be substituted by sodium chloride and that sodium and chloride concentrations of about 12 mmol (276 mg/l Na plus 426 mg/l Cl) are still acceptable.

In recirculating systems, the accumulation of sodium will be more critical than that of chloride, as sodium is absorbed less readily than chloride. At a concentration in the root environment of 276 mg/l Na about 23, 7 and 30 mg per litre of water is absorbed by tomato, sweet pepper and cucumber, respectively. Higher sodium concentrations than 276 mg/l will result in accumulation.

Sonneveld's data clearly contradict those of Adams. According to Adams work presented above, the salinity yield threshold value for tomato wouuld be beyond 6.2 mS cm^{-1}. Sonneveld suggests the contradiction may be caused by differences in growing conditions. Under conditions promoting vegetative growth eg low light, low temperatures, tomato plants grow too vigorously and then high salinity will improve fruit formation.

The practical conclusions of Sonneveld's work are summarised below:-

Tomato

1. Yields of tomato declined if the EC was above 2.5 mS cm^{-1} for a July to November crop and 2.9 mS cm^{-1} for a January to September crop.

2. The effect was the same whether the conductivity was raised by additional nutrients or sodium chloride.

3. Blossom-end rot increased with increasing EC but at an EC of 3.7 BER was significantly lower where 444 mg/l chloride was added compared with 178 mg/l (crop 1 only).

4. Shelf life improved with increasing EC.

5. Russetting decreased with increasing EC.

6. Acids and refraction (sugars) both tended to increase with increasing EC.

Cucumber

1. Yields of cucumber declined if the EC was above 2.3 mS cm^{-1} for an early crop and 3.5 mS cm^{-1} for a replant crop.

2. The highest sodium chloride concentrationn in the replant crop significantly reduced fruit yield as compared to the highest nutrient concentration. Slight specific yield reductions were also found in the first crop. All this indicates a tendency towards specific sensitivity to sodium chloride, which has also been found for soil-grown cucumbers. (Sonneveld and van Beusekom, 1974).

3. Colour index improved with increasing EC.

4. Shelf life improved with increasing EC.

Pepper

1. Yields of pepper declined if the EC was above 2.8 mS cm^{-1}.

2. There was a slight specific yield decrease attributable to sodium chloride but this might be explained by the higher percentage of fruit affected by blossom-end rot.

3. Blossom-end rot increased with increasing EC values.

4. Russetting and green spot decreased with increasing EC values.

If the EC in the root environment is maintained at a constant level and other nutrients supplied at sufficient concentrations, yields should not be affected by the accumulation of sodium chloride and sulphate in the recirculating solution. Further experiments at PTG Naaldwijk were designed to clarify the effects of different nitrate, sulphate and chloride ratios in the root environment on yield and fruit quality of tomato grown in a recirculating system (Nukaya et al, 1991). The concentrations ranged from 84 to 224 mg/l (nitrate), from 160 to 320 mg/l (sulphate-S) and from 107 to 462 mg/l (chloride). The electrical conductivity was kept constant at 3.5 mS^{-1}. Cumulative yield to the end of May and 5 October did not differ significantly between treatments in either number, weight or average weight of fruits (January planting).

High chloride increased the incidence of gold spot: the incidence of gold spot ranged from 25 to 30% in 107 mg/l chloride treatments and from 38 to 47% at 462 mg/l chloride. This trait was also noticed in experiments at HRI Efford (Fussell and Hand, 1994). However, it seemed that with increasing sulphate-S and especially chloride, less blossom-end rot (BER) appeared. At the end of the experiment, the percentage of BER fruits was 7.5 to 9.2% at 107 mg/l chloride but was only 5.7 to 6.9% in the 284 to 426 mg/l treatments. Most blossom-end rot occurred in August and September. Russetting was not affected by the treatments.

Shelf life tended to decrease with increasing chloride and sulphate-S. This was partly due to the increased incidence of gold spot which is known to adversely affect shelf life. Soluble solids and acid content of fruit were not affected by the treatments. Plant growth was not measured but all plants appeared to grow vigorously and there were no toxicity or deficiency symptoms. Contents of chloride and calcium in young leaves tended to increase with increasing chloride content in the root environment. The same trend was noted for chloride in fruit, but the effect on the calcium content of fruit was not substantial. However, unlike Adams, the whole fruit was analysed and not just the distal portion. The leaf contents of total N, sulphur and elements other than calcium and chloride were not affected by the anion ratios in the solution. Since both BER and gold spot were affected they concluded that calcium uptake and distribution into the fruits were affected by the anion ratios. No symptoms of nitrogen deficiency were observed in treatments with 85 mg/l NO_3-N; nutrient solutions were adjusted to the set concetrations once a week.

In non-recirculation rockwool systems the EC is always lower immediately under the drippers compared to the area between drippers. In tests carried out at PTG Naaldwijk (Voogt and Van der Elzen, 1989) the root systems of tomato plants were divided in half with each half exposed to different EC values.

The experiment showed that for maximum yield, at least part of the root system had to be in solution of 2.5 mS cm^{-1}. There was no effect on yield if the other half of the root system was at a higher or lower EC. However, fruit quality was impaired if half of the roots were exposed to a low EC. Water uptake fell sharply if the EC rose above 2.5 mS cm^{-1}. Water uptake was more or less the same when a low EC was combined with the standard EC as for the standard EC alone. Nutrient uptake increased with increasing EC. Total nutrient uptake per plant did not differ significantly between treatments as one half of the roots compensated for the other. Specialisation of roots occurred such that some roots adapted to take up water preferably while others adapted to take up nutrients.

The accumulation of sodium, chloride or sulphur in the slab need not cause problems if the roots can resort to lower EC sites to draw water from. This will be of particular significance to `V'-systems.

There were also clear effects on root development: the higher the EC, the coarser and less branched the roots.

In HDC-funded trials at HRI Efford, Fussell and Hand, (1994) noted that leaf expansion appeared to be reduced at 65 mg/l applied N. Martinez and Cerdä (1989) looked at the combined effect of sodium chloride and nitrogen nutrition on nitrate reductase activity in tomato and cucumber grown in solution culture. Nitrate reductase is one of the various biochemical factors limiting growth since it plays a key role in the process of nitrate assimilation in higher plants. It is well documented, with different crops and experimental conditions, that high sodium chloride in the growth media reduces nitrate uptake.

Two levels of sodium chloride equivalent to 92 or 1380 mg/l sodium and 142 or 2130 mg/l chloride were combined with four N levels (28, 84, 140, 210 mg/l). Separate experiments were conducted for each plant species using only nitrate-N or ammonium plus nitrate-N in the ratio 2:1. Not surprisingly, leaf growth was inhibited by the high salinity treatment for both tomato and cucumber. The degree of inhibition was related to the N source used. A 24% reduction in leaf growth occurred in tomato plants treated with 140 mg/l N when nitrate was used as the N source. However the combined ammonium/nitrate treatment gave a 40% reduction. In contrast, the leaf growth inhibition in cucumber plants was 50% and 36% when nitrate only or nitrate plus ammonium were the N sources, respectively. In general maximum leaf growth occurred at 210 mg/l for cucumber and 140 mg/l for tomato (plant harvested at about 28 days).

Nitrate reductase activity (NRA) decreased in leaves of both plant species as salinity increased. Within each salinity level, NRA increased with the concentration of nitrate-N in solution. It appeared that the NRA was affected directly by the presence of excessive sodium chloride in the solution either by interfering with the uptake of nitrate by roots, or by inhibiting nitrate transport. It appears that the salinity effect on leaf growth could be due to the inhibition of NRA in the leaves.

In both plant species, leaf chloride accumulation increased with solution sodium chloride concentration. When the N source was nitrate, leaf chloride contents tended to decrease with increasing nitrate level. The chloride contents of tomato leaves were about 2-3 times higher than for cucumber leaves.

NRA was greater in tomato than in cucumber leaves; this could be related to the greater tolerance of tomato to salinity. In an experiment looking at the effects of sodium chloride on greenhouse cucumbers, Chartzoulakis (1992) found that in all plant parts chloride content was much higher than sodium; visible salt injury symptoms were developed when sodium and chloride content in the leaves exceeded 0.4% and 3.6% in the dry matter, respectively.

Drew *et. al* (1990) reported salt-induced inhibition of CO_2 fixation for cucumber grown in hydroponics. This was associated with accumulation of sodium and chloride and reduction of potassium in the leaves. The net assimilation rates at saturating concentrations of CO_2 provide a measure of the maximum rate of CO_2 fixation attainable. Fixation was inhibited when plants were exposed to 888, 1775 and 3550 mg/l chloride, especially at the highest concentration, where chloroplasts virtually ceased to respond to additional CO_2. Rates of gas exchange for single leaves as measured in this experiment may not be an accurate estimate of those operating in an undisturbed greenhouse because of boundary layer differences. However, such laboratory estimates should represent trends.

Net photosynthesis of plants treated with 888 mg/l chloride was somewhat more inhibited than with 1775 mg/l. The explanation may be that, at the higher concentration, transpiration is inhibited by partial stomatal closure and by the lower osmotic potential of the nutrient solution. Less sodium and/or chloride would then be carried to the leaves with the transpiration stream than at the lower concentration, where transpiration was inhibited. This explanation was borne out by the sodium concentration in the leaves, which were greater at 888 mg/l (575 mg/l sodium) than at 1775 mg/l chloride (1150 mg/l sodium). At concentrations at sodium chloride which are highly toxic to salt-sensitive cucumber (2300 mg/l sodium, 3550 mg/l chloride), damaging amounts of sodium and chloride accumulate in leaves whatever the transpiration rate may be.

In 1992 an HDC funded trial began at HRI Efford to examine the influence of reduced nitrate input on tomato (Fussell and Hand, 1994). Potassium nitrate was partially substituted by potassium chloride, calcium chloride or calcium nitrate. The percentage Class I fruit was not reduced when using chloride as a substitute for nitrate. Although not statistically significant, the use of potassium chloride increased the total yield to the end of the season by 2.4 kg m^{-2}. Higher levels of gold spot were recorded from Week 23 onwards where calcium salts were added to the base feed. Where chlorides were used, the nitrate-N level in the applied feed was only reduced from 295 to 210 mg/l. Therefore a further study was carried out in 1993 to evaluate the degree to which nitrate inputs and hence emission to the environment can be reduced.

Four nitrate levels in the applied feed of 65, 125, 185 and 247 mg/l were achieved by augmenting a base feed of 1.25 mS cm^{-1} with one of four mixtures of potassium chloride and potassium nitrate to achieve an EC of 2.8 mS in the applied feed. To investigate possible interactions between nutrition and root zone volume, all four regimes were applied to a crop of cv. Pronto (sowing date 3.11.92), grown both as a conventional double row and a V-system. As in 1992 treatments commenced just prior to first pick (Week 7) as the aim was to look at their effects on fruit quality and not early season growth.

In contrast to expectations, reducing the nitrate input to 65 mg/l had no effect on yield. Leaf colour and canopy development appeared very similar across all four treatments. However, leaf expansion appeared to be delayed where the nitrate input was reduced. The maximum applied level of chloride was 600 mg/l. Although this is much lower than the levels tested by Martinez and Cerdá (op cit) it is possible that the combined effect of high chloride and low nitrogen was reducing leaf growth via a reduction in nitrate reductase activity and/or inhibition of net CO_2 fixation (Drew et al op. cit).

Increased chloride level in the feed resulted in higher chloride levels in the fruit. However, the taste characteristics were largely unaffected, with taste panellists failing to express a preference. It may be the enhanced sodium content rather than chloride that panellists can detect when tomatoes are grown with increased sodium chloride.

The lack of any yield reduction from the 65 mg/l N treatment prompted an examination of the theoretical nitrogen offtake of a tomato crop (Table 8.25).

Table 8.25 Estimated nitrogen balance for a tomato crop

Plant Part	**Fresh weight (kg/m^2)**	**% DM**	**Dry Matter (t/ha)**	**Wt of plant part as % of total DM**	**% N**	**N -offtake kg N/ha**
Fruit (1) (inc waste)	48	5.4	25.9	67	1.7	441
Leaves (2)	5.71	10.7	6.1)		3.5	214
			)	17		
Sideshoots (2)	0.41	9.8	0.4)		4.7	19
Haulm (3)	3.12	19.4	6.1	16	2.0	121
TOTAL			38.5			795

Data Source (1) HRI Efford
(2) HRI Stockbridge House
(3) Vaughan (1989)

These data are broadly in agreement with those of Cockshull (1993, pers comm) who reported 69% of the dry matter in the fruit, 18% in leaves and 13% in stems out of a total of 35 t/ha dry matter.

Table 8.2.6 Estimated N inputs for low N treatment (65 mg/l applied N) HRI Efford 1993 HDC Project No PC55a

Feed Input	Litres/m^2	N conc mg/l	N kg/ha
Week 1 to Week 6 (inc)	252	450	1134
Week 7 to Week 43 (inc)	1148	65	746
Total	1400		1880
Crop Offtake (total yield 43 kg/m^2)			712
Implied Loss in run-off			1168

It can be seen clearly in Table 8.26 that the largest proportion of nitrogen was lost in the early season where although amounts are small, the nitrogen concentration is relatively high. The applied nitrogen in the Efford trial is well in excess of crop requirement. Marks (1993, pers. comm.) calculated the N applied per ha according to the N concentration in the applied feed and the feed volume applied (Table 8.27). If the N offtake of a long-season tomato crop is approximately 795 kg/ha N then N concentration/feed volume combinations above the diagonal line in Table 8.27 should be in excess of crop requirement. Clearly, the nutrient balance approach is an essential part of any nitrogen response trials.

Tomato is the only crop where high EC is used during the propagation and early season phases to control growth. There is little information on the effects of low nitrogen before picking. Holder (1987) carried out a small observation trial on tomato plants up to first anthesis (Table 8.28). The EC was raised by addition of sodium chloride. Growth was reduced at 88 mg/l N compared to 176 mg/N.

Trials at HRI Stockbridge House and at the Scottish Crops Research Institute examined the scope for using low nitrogen to control early growth of tomato. Although the technique was successful for perlite grown crops in the Clyde Valley, it never gained acceptance elsewhere; it was crucial (and difficult) to pinpoint the time to change from the low N feed to the main season feed. A low N/high EC feed produced by using a combination of sodium and potassium chlorides appears to be the most promising of limited nitrate pollution during propagation and early growth and further work on this topic is required.

Table 8.27 Amount of N applied per ha according to the N concentration and volume of the applied feed

FEED VOLUME (m litres/ha)	7	10	12	14	17.5
					60
DRAINAGE (%)	Nil	30	40	50	
N CONC (mg/l)	N APPLIED (kg /ha)				
50	350	500	600	700	875
75	525	750	900	1050	1313
100	700	1000	1200	1400	1750
125	875	1250	1500	1750	2188
150	1050	1500	1800	2100	2625
175	1225	1750	2100	2450	3063
200	1440	2000	2400	2800	3500
250	1750	2500	3000	3500	4375
300	2100	3000	3600	4200	5250

after Marks, 1993

Table 8.28 The effect of nitrate concentration and electrical conductivity on the growth of tomato seedlings

Fresh weight (g.plant -1)

	Nitrate (mg N.l^{-1})		EC mean
EC (mS cm^{-1})	88	176	
2.5	97.5	118.2	107.9
5.0	76.8	87.2	82.0
N mean	87.2	102.7	

Dry Weight (g.plant -1)

	Nitrate (mg N.l^{-1})		EC mean
EC (mS cm^{-1})	88	176	
2.5	11.1	12.9	12.0
5.0	9.2	11.0	10.1
N mean	10.2	12.0	

& Dry Matter

	Nitrate (mg N.l^{-1})		EC mean
EC (mS cm^{-1})	88	176	
2.5	11.3	11.0	11.2
5.0	12.1	13.2	12.7
N mean	11.7	12.1	

Nitrate content of rockwool cubes 24h after watering

EC (mS cm^{-1})	Nitrate (mg $N.1^{-1}$) 88	176	EC mean
2.5	4.0	69.5	36.8
5.0	8.5	112.5	60.5
N mean	6.3	91.0	

Notes: Variety; Counter
Sown; 29.8.87
Treatments applied; 7.9.87
Harvested (first anthesis); 2.10.87
after Holder, 1987
Efford EHS (now HRI Efford)

There is a gulf between common commercial practice and the theoretical crop requirement. The HDC-funded trials at Efford have shown enormous scope for reducing N inputs. As a result, the ADAS recommendations for growers have been reduced to 200 mg/l for the early season and 125 mg/l for the main season. These figures may well be reduced again pending results from the 1993/94 trial. Low nitrate treatments will commence at slab contact and savings in N should be much greater. As well as benefits to the environment, there are large savings to the grower. It has been estimated that by reducing the nitrate of feed to 250 mg/l N in the early season and 150 mg/l in the main season a grower could save over 25% fertiliser costs, equivalent to £2,700 per ha. There are however few drawbakcs. The maximum admissible concentration (MAC) for chloride in drinking water is 200 mg/l. In the long term, the NRA may be concerned about run-off from greenhouses containing in excess of 1,000 mg/l chloride.

Most of the work to date has been carried out on tomatoes. Sonneveld and Van der Burg (op cit) observed that peppers do not absorb much sodium or chloride and the incidence of blossom-end rot was increased when sodium chloride was added to the feed. It has been pointed out by Martinez and Cerdä (op cit) that cucumbers are more sensitive to salinity than tomatoes; O'Neill (1993) showed that there was no yield penalty associated with chloride levels of 300 mg/l (achieved by adding calcium chloride). Further work on cucumbers and peppers is required.

9. DISCUSSION

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Regulatory framework

"Nitrate" is a legislative as much as an environmental problem" (Addiscott et al, 1991). Although the health risks associated with nitrate are far from proven (Section 3.11) the EC Drinking Water Directive requires that drinking water should contain no more than 50 mg/l NO_3 11.3 mg/l NO_3-N). This has been followed by the Nitrate Directive which in addition to aiming to limit nitrate contamination of drinking water also seeks to prevent harmful effects of nitrate on surface waters.

As well as Directives from the EC relating to drinking water quality there are a large number of laws controlling pollution (Section 2). It is already an offence to allow water from a piped drainage system underneath a nursery to enter a watercourse if that water contains a high concentration of nutrients and/or pesticides.

As the Nitrate Directive includes diffuse losses of nitrate as well as point source pollution it may well have a considerable impact on intensive horticulture. At the time of writing, the extent of the Nitrate Vulnerable Zones has yet to be announced, but this is expected to happen before June 1994. A consultation document should then be sent to farmers and growers in the designated areas. A lot depends on what is defined in the action programmes with reference to intensive horticulture (see Section 2.5 for timetable).

Other regulations control the storage and use of pesticides and abstraction of water. New nurseries in certain areas already require environmental assessments to comply with planning law. It is necessary in some cases to prepare an "Environmental Statement" before applying for planning permission for some major agricultural developments such as large new pig and poultry units. New nurseries using run-to-waste rockwool systems could be compared to intensive livestock units in terms of nitrate loss and could be subject to the same kind of requirements, at least in Nitrate Vulnerable Zones.

The Nitrate Sensitive Areas Scheme which has recently been extended to 30 new areas (Fig 2.1) is not likely to attract any hydroponic growers as the maximum compensation is only c. £600/ha.

Environmental impact

Nitrate is very soluble and occurs at low levels in most surface and underground waters as part of the natural "Nitrogen Cycle". However, concentrations in these waters have been increasing steadily for the past 30 years. In some areas overlying chalk it takes decades for rainfall percolating down through the soil to reach the aquifer; thus the substantial amount of nitrogen released by ploughing-up old grassland after the war has still to make an impact. In contrast, in areas over fissured limestone or sandstone, the residence time is five years or less. Thus any changes in agricultural practices affect nitrate concentrations in borehole water over a range of time scales depending on the underlying geology.

Mathematical models have been used to predict what will happen in some catchments if current practices continue and also to assess the possible effects of changes in land use. Financial analysis has indicated in some cases that control of agricultural activities is the cheapest option, compared to water treatment to remove the nitrate or blending with low-nitrate supplies. There are some examples of actual studies where changes of land use have reduced nitrate leaching and further evidence is expected from monitoring of Nitrate Sensitive areas.

Excess amounts of nitrate and phosphate in the environment lead to eutrophication (section 3.12). There has been a general decline in the quality of estuaries since about 1980 and an overall net downgrading of river length in England and Wales since 1985. Some of this is due to sewage treatment works being in breach of their consents (about 7% in 1991). The number of *reported* water pollution incidents in England and Wales is on the increase. The number of major water pollution incidents caused by farming went down from 239 in 1990 to 99 in 1991, but the number of prosecutions increased from 123 to 159, respectively (Section 3.14). Pollution offences are regarded very seriously and carry a penalty of up to £20,000 in the Magistrates Court, plus damages (Section 2.1). Harris (1991) showed in a theoretical desk exercise that discharges from horticulture point sources such as nurseries growing containerised HONS or hydroponic crops on a run-to-waste system could become the dominant source of nitrate in some surface waters during the summer (Section 3.14).

There has been a decline in water use by industry due to increased efficiency, recycling and the contraction in manufacturing. In contrast, the rate of water abstracted for spray irrigation has been increasing, particularly in the dry years of 1990 and 1991 (Section 3.17). Although relatively small in total, abstractions for spray irrigation may have a significant impact on available resources as such abstractions are highest when water resources may be already stretched. At present, glasshouse growers are exempt from restrictions during drought orders, but it is an offence to abstract water without a licence or not to comply with the terms of a licence. As water low in nitrate becomes more scarce, the NRA is likely to look closely at abstraction as well as disposal.

Pesticides

The EC and national standard for any individual pesticide in drinking water at the time of supply is 0.1 µg/l and 0.5 µg/l for total pesticides and related products. These standards are not related to the toxicity of individual pesticides and there are analytical difficulties for some pesticides. The most frequently detected pesticides in water are all herbicides. The origin of this contamination is not necessarily agriculture. Atrazine is used almost entirely on roadside verges and railways and approximately one-third of the use of simazine is attributed to non-agricultural purposes (DoE, 1993). Pesticide pollution from hydroponic crops could affect both surface and ground waters. Both may be used for abstracting drinking water. The two main hazards from pesticide pollution of water are: damage to the aquatic environment and contamination of drinking water.

An examination of the data relating to the three active ingredients approved for application to the root zone of hydroponic crops showed that these fungicides are unlikely to pose a serious pollution problem when used correctly but monitoring is required to determine the actual losses from hydroponic crops (Section 3.2). In an HONS experiment at HRI Efford two herbicides (oxadiazon and simazine), one fungicide (furalaxyl) and one insecticide (fonofos) were applied at recommended rates. Considerable leaching of applied pesticides was observed with concentrations well in excess of the EC Drinking Water Standards throughout the whole season following application.

An expert system which predicts the potential for a pesticide to contaminate surface or groundwater sources is proposed for the UK (Carter et al, 1991). The system is intended to provide a unified national approach to the initial screening of pesticides and also as a practical tool for local catchment and source management.

Soil nutrient loadings

Soil mineral N (SMN) is a measure of nitrate plus ammonium-N (Section 4). Values for SMN after rockwool cucumber crops varied from 97-712 kg N/ha in the rows to 251-

1319 kg N/ha under the paths. Values under a soil crop were only 11% lower. For a rockwool tomato crop corresponding values were 230 kg N/ha (path) and 356 kg N/ha (row). Values for a soil-grown tomato crop on the same nursery were 967 and 1177 kg N/ha, respectively. These figures are much higher than those found in most other agricultural and horticultural situations (Table 4.2). Values in excess of 900 kg N/ha would only occur in exceptional cases, for example where a field had been used as a "sacrifice area" for disposal of large quantities of poultry manure or pig slurry for a number of years. Such practices contravene the Code of Good Agricultural Practice for the Protection of Water (MAFF, 1991). The *potential* for loss of nitrate-N is extremely high if the soil is leached after a succession of rockwool or soil-grown crops. For rockwool crops, much NO_3 -N is lost in run-off (Section 5) as well as leaving high residues in the soil. It is possible that some nitrate is being converted to gas (nitrogen and nitrous oxide) a process known as denitrification (see Section 3.16). Waterlogged soils kept at 25°C under laboratory conditions and supplied with plenty of easily-decomposable organic matter may result in losses of 30 kg N/ha/day (Addiscott, et al, 1991).

The zinc content of hydroponic solutions is unlikely to pose a pollution threat to water. However, the extractable zinc content of the Lea Valley rockwool and soil sites were 16-27 times greater than the median value of agricultural soils (Archer and Hodgson, 1987). At Stockbridge House extractable zinc values in the soil or rockwool glasshouses were no higher than an adjacent area outside, so the Lea Valley sites may have been contaminated.

Soil boron values measured in this study show no evidence of accumulation in the soil. The concentrations recommended in hydroponic feeds (0.3-0.5 mg/l B) are less than the guide level for drinking water (1.0 mg/l).

Case studies of hydroponic nurseries

Results from the seven case studies showed widely different nutrient losses between different systems (eg NFT versus run-to-waste rockwool) and between different growers using the same systems for the same crop. Water use varied from 663 litres/m²/year (NFT tomatoes) to 2080 litres/m²/year (run-to-waste rockwool tomatoes) (Table 5.2). Three growers provided water consumption figures from mains water meters which should be very reliable as they are checked by the water supply companies.

Assuming the NFT tomato system (Grower No 4) had no leaks, a water consumption figure of 663 litres/m²/year must be close to the theoretical water requirement of a long-season tomato crop (yield 48.4 kg/m²; 192 tons/acre). Extrapolating to 200 tons/acre (50 kg/m²) gives 691 litres/m²/year. This figure can be compared to data from Holland. For the 1988/89 growing season, data was collected from 83 glasshouse holdings with various crops and growing systems (Nienhuis vernooij, 1990). Apart from run-to-waste and recirculating systems, there was an intermediate type where the solution was run-to-waste for the early part of the season and later re-circulated; this was termed "seasonal re-circulation". On many nurseries there were no officially calibrated water meters installed. However, growers kept very accurate records of the amounts of fertilisers used, and these were used to check the reliability of the water input figures. From this it emerged that some water meters were inaccurate by +/- 20%. As with the present study, growers often under-estimated the amount of run-off. Results from the Dutch study are summarised in Table 9.1. Data from one cucumber nursery with total re-circulation showed a water use of about 680 l/m². The run-off from run-to-waste systems in the Dutch study was very much lower than values recorded in the present study (25-66%).

Table 9.1 Input of fertilisers (anhydrous) and water; discharging and (calculated) uptake of water in glasshouse establishments (crop year 1998/1989).

(after Nienhuis and Vernooj, 1990)

Crop	System	No of holdings	Fertiliser	Water	Run-off (c)	Water Uptake (d)
			input (a) kg/ha	input (b) l/m^2	%	l/m^2
Tomatoes	mainly re-circ	5	8974	804	5	767
	seasonally re-circ	3	14056	926	13	804
	run-to-waste	8	15354	969	18	792
Cucumbers	mainly re-circ	7	10423	723	5	690
	seasonally re-circ	3	13859	964	7	892
	run-to-waste	6	15060	968	16	816
Peppers	totally re-circ	4	8160	666	<1	664
	mainly re-circ	7	8800	756	7	702
	seasonally re-circ	7	10288	742	12	654
	run-to-waste	7	16044	1012	24	766

(a) Fertiliser input is shown as anhydrous salts. For conversion to kg fertiliser in solid form, the quantities shown must be increased by approximately 25%.

(b) The figure shown under "input of water" is the quantity of "primary water". This is water, not previously used, that is introduced into the feeding system, eg from the rainwater storage tank or reservoir.

(c) As percentage of input water.

(d) The uptake of water is a figure calculated from the input of "primary water" and the quantity of water discharged. Any inaccuracies in those two figures will affect the water uptake figure.

However, if the water use calculated from nurseries with total re-circulation is used (peppers 664 l/m^2; cucumbers 680 l/m^2) then run-off figures from run-to-waste crops become 34% and 30% respectively. There were no reliable data on water use from the one tomato holding which was totally re-circulating, but data from Grower No 4 in the present study and from Bailey (Table 9.2), imply that run-off values for the Dutch run-to-waste tomato nurseries were *c.* 32-35%.

Losses of fertiliser were even greater than run-off values would suggest: run-to-waste nurseries consumed 50% more fertiliser than those in the totally re-circulating group. The NFT tomato grower in the present study (No 4) used less than 25% of the potassium nitrate plus potassium chloride used by Grower No 1, though he used 40% of the water used by Grower No 1. Even allowing for the fact that the NFT grower averaged 305 mg/l K in the re-circulating solution compared to 431 mg/l for the run-to-waste system of Grower 1 there is still a substantial difference in fertiliser use.

In the case of re-circulating tomato crops and especially cucumber crops the uptake of fertiliser was much higher than for peppers (Table 9.1). This is probably due to the greater production of dry matter for tomatoes and cucumbers (Table 9.3). In the Dutch study, differences in water and fertiliser use between re-circulating and run-to-waste nurseries were greatest in Summer. 1989 was a very dry summer and most growers in the survey had to top up their reservoirs with mains water which contains a lot of sodium and necessitates more flushing. As a precaution the drainage water was run-to-waste on most holdings in the survey when the sodium content reached 5 mmol/l (138 mg/l. However, one pepper grower in the total re-circulation group allowed the sodium concentration to far exceed this limit with no apparent damage or loss of yield.

Research workers in England have provided further estimates of the water required by a tomato crop to meet its transpiration demand. Using a humidity programme developed by Jolliet, Bailey has calculated a value of 580 litres/m² for water transpired (Bailey 1993, pers comm). To this must be added the water retained in leaves, fruit, etc (Table 9.2).

Table 9.2 Estimated Water Requirement of a Tomato Crop

Plant part	Fresh Weight kg/m²	Dry matter %	Water Requirement l/m²
Fruit (1) (inc waste)	48.0	5.4	45.4
Leaves (2)	5.7	10.7	5.1
Sideshoots (2)	0.4	9.8	0.4
Haulm (3)	3.1	19.4	2.5
Transpiration demand (4)			580
TOTAL			633

(1) HRI Efford
(2) HRI Stockbridge House
(3) Vaughan (1989)
(4) Bailey, 1993 (pers comm)

The total dry matter production for fruit of the three main edible crops are shown in Table 9.3. This does not take into account the vegetative production, but harvest indices (ie ratio of fruit dry weight to total dry matter production) should not be very different between these crops. Taking a theoretical crop water use of 700 litres./m² implies that some of the growers in the survey are under-estimating actual losses. (Table 9.4).

Table 9.3 Dry Matter Production (fruit only) of Main Edible Hydroponic Crops

	Fresh Yield t/ha	Dry Matter %	Yield (Dry Weight) t/ha
Tomatoes	500	6.0	30
Cucumbers	600	4.0	24
Peppers	250	6.7	17

Table 9.4 Estimated % run-off compared to theoretical values for three tomato growers using mains water

Grower No	Growing System	Water Use l/m²/year	Estimated run-off (1) %	Theoretical run-off (2) %
1	Run-to-waste rockwool	1548	50-60	55
4	NFT	663	Nil	Nil
6	Run-to-waste rockwool	2083	50	66

(1) As % of applied solution (growers' estimate)

(2) Assuming theoretical water requirement of 700 litres/m²

Grower 6 sowed nearly a week later than Grower 1's latest sowing date and picked 30 tons/ac (75 t/ha) less tomatoes but still used 535 litres/m² more water. Grower 6 also had a much lower plant population that the other two (10,750 compared to 13,000-14,000 after sideshoots had been taken). Analysing the watering policies of the seven growers in the survey suggests that the following factors are likely to increase percentage run-off:

1. Large number of waterings per day (>20).
2. Large variability in output of drip nozzles (>20%)
3. Less than 100 MJ used to trigger 100 mls/plant or more of irrigation.
4. Low output per nozzle < 2 litres/hour.
5. Lack of proper monitoring and maintenance of irrigation equipment.
6. Lack of accurate monitoring of water used vs run-off.

There was no apparent relationship between the type and density of rockwool and the amount of run-off. However, the Aggrofoam slabs used by Grower 7 required a maximum of 25-30 irrigations per 24 hours, compared to only 15 for the Grodan rockwool. Run-off was also higher for the foam slabs (30-35% compared to 25-30% for rockwool).

Large differences in irrigation equipment and policy tended to swamp any patterns which might have emerged due to differences in glasshouse environment.

Earlier experiments at HRI Stockbridge House (cucumbers) and HRI Efford (tomatoes) have shown no yield benefits from excessive overwatering (Table 9.5). Growers 3 and 7 (run-to-waste cucumbers) and Grower 5 (run-to-waste tomatoes) all claimed run-off figures of 35-35%. Unfortunately, only Grower 7 gave a water use figure (1033 litres/m²). If the theoretical requirement of long-season cucumbers is c.700 litres/m² then a water-use figure of 1033 litres/m² does imply a run-off percentage of 32%. The results from the case studies therefore imply that a run-off of 30% is achievable in practice. Any run-off in excess of this is increasing pollution and adding to the growers' costs.

Table 9.5 Effect of Different Amounts of Excess Watering Efford EHS (1) 1986

Tomatoes **Level of excess irrigation**	**Yield (kg/sq m)**	
	to end May	**total to Sept**
12%	14.1	41.2
40%	14.2	41.7
68%	13.9	41.4

(1) now HRI Efford

In run-to-waste rockwool systems the performance of the trickle irrigation is the major obstacle to reducing run-off. Growers in the survey reported 10% variability at the beginning of the season but up to 50% at the end. Some of the variability will be due to incorrect installation eg nozzles not all at the same level in an irrigation zone.

Filters reduce blocked nozzles

Mains water has to meet drinking water standards for turbidity and hence should not cause blockages, although storage facilities may cause problems. Borehole water also can be very clean. Roof water can be very dirty, especially after a long, dry period. Grower 5 used roof-water collected in an uncovered reservoir and reported up to 50% variability between drippers. River or stream water usually carries suspended particles. Grower 7 used river water but reported only 10% variability between drippers. One explanation for this apparent discrepancy could be the type of filtration used. Roof and river water are usually stored in large, uncovered lagoons. This allows most of the particles to settle out but most lagoons suffer from a build up of algae which will block filters and affect pump performance. There are three main forms of filtration:-

- *Wire Mesh*

  Cheap, (c. £140) simple and work well as long as the dirt load is very small. All irrigation systems should have a fine mesh filter, after all of the mixing and dosing equipment to remove particles of undissolved fertiliser.

- *Sand Filter* (c.£420)

  Sand filters contain a range of grades of sand to trap progressively smaller particles. Sand filters are good for large amounts of small particles (e.g. algae) but become clogged quickly with large particles.

- *Self-cleaning rotary filter* (c.£650)

  This type of filter can remove large quantities of large particles.

For some nurseries using roof water stored in a lagoon all three filter systems may be required.

Irrigation design and strategies

Another way of reducing the problem of variability is to have a single nozzle for each plant plus a spare in each slab. Two litre/hour nozzles are up to 35% cheaper than those with a 4 litre/hour output. Smaller nozzles might make some saving at installation but over their working life any savings are negligible. Large nozzles have larger orifices and should be less inclined to block. Capillary emitters should also be less prone to blocking than labyrinth-types due to the larger internal dimensions but some capillary lines show more variation when new than "button" or labyrinth types.

The performance of an existing system can be improved by proper treatment at the end of the season with nitric acid (to remove limescale) hypochlorite to remove bacterial slime and high-pressure water.

The design of the growing system (and the glasshouse) demands a fall along the length of the rows to allow for drainage, particularly if re-circulation is required. However, for optimum performance the lines of nozzles must be more or less level. A slight slope may result in water volumes at the bottom end being twice those from the top for a typical irrigation cycle (Stearne, 1994 pers. comm.).

Current practice is to trigger irrigation by light received or time, or a combination of both. New methods of scheduling irrigation may match crop needs more closely and reduce run-off. Various forms of "start trays" are available which monitor the amount of run-off, the electrical conductivity of the run-off, the weight of a slab or the moisture content of a slab but these tend to be expensive and there is always the problem of how many are required and where to site them to obtain values representative of the whole crop. Jones and Sutton (1992) reviewed some new techniques. Modern instruments can provide early warning of water stress (and hence potential yield loss) before any visible wilting symptoms. Some methods are still only of use as research tools, such as the acoustic detection of xylem cavitation or the use of stem diameter gauges, and require further development. According to Jones and Sutton, the most immediately promising approach is based on the sensing of crop canopy temperatures using infra-red thermometers. This depends on the fact that one of the first responses to water stress is for the stomata to close, with consequent reduction in evaporative water loss. This results in an increase in leaf temperature. There can be significant differences between varieties possibly due to root development and stomatal behaviour.

Nitrogen and phosphorus losses from hydroponic systems

Harris and Burbridge (1991) estimated losses from container HONS at 80-360 kg N/ha, but even these losses are modest compared to those from run-to-waste systems in the present survey (Table 9.6). Grower No 7 (cucumbers) had the lowest water consumption for a run-to-waste system and the lowest nitrate-N concentration but still the calculated N loss was 477 kg N/ha/year. The other cucumber grower had no record of water consumption; assuming that his measured run-off percentage was accurate, the volume of run-off was very close to that of No 7. However, nitrate-N losses were considerably greater at just over 1000 kg NO_3 -N per ha. This was because Grower No 3 used much higher N levels in the feed than Grower 7 (334 mg/l N versus 154 mg/l N). The recommended N level for cucumbers is 180 mg/l N. At 30% run-off this would result in an annual nitrate loss of 540 kg N/ha. Grower 7 achieved a good yield for cucumbers (118 cucumbers/m^2), so there would appear to be scope for reducing the recommended N level for cucumbers.

Losses from run-to-waste tomato crops in the survey were even higher. Grower 6 with a calculated run-off of 66% plus excessively high slab NO_3-N levels of nearly 400 mg/l,

Table 9.6 Estimate of nitrate-N and phosphorus losses

	1	2	3	4	5	6	7	
Crop	Tomatoes	Peppers	Cucumbers	Tomatoes	Tomatoes	Tomatoes	Cucumbers	
Hydroponic system	run-to-waste rockwool	recirculating rockwool	run-to-waste rockwool	NFT	run-to-waste rockwool	run-to-waste rockwool	run-to-waste cucumbers	
Date planted	16-17-12.91	19-26-11.90	Mid-Feb 91	24-26.11.91	4.12-early Jan	4.12.91	4.12.91	
First pick	10.2.92	6-7 3.91	15-20 March	23.2.92	3rd wk Feb	10.3.92	mid-Jan	
No of weeks at high EC	8	12	-	15	10	14	-	
Water used in this period litres/m²*	279	170 (1)	-	119	180 (1)	375	-	*Assumes tomatoes receive 18% of total irrigation for the year Dec-early Feb
% run-off	55	30	-	0	30	66	-	
Volume of run-off litres/m²	153	51	-	0	54	248	-	
Mean No$_3$-N conc mg/l	255	379	-	83	293	413	-	
Early season No$_3$-N loss, kg/ha	390	193	-	0	158	1024	-	
Date irrigation ceased	31.10.92	9-15 10.91	25.9.91	w/e 19.10.92	mid-Oct	1.11.92	mid-Oct	
No of weeks at main season EC	38	37	27	32	34		39	
Water used in this period litres/m²	1269	572 (1)	1000 (1)	544	820 (1)	1708	1033	
% run-off	55	5	30	0	30	66	30	
Volume of run-off, litres/m²	698	29	300	0	246	1127	310	
Mean NO$_3$-N conc mg/l	215	303	334	249	268	393	154	
Main season NO$_3$-N loss, kg/ha	1501	88	1002	0	659	4429	477	
Early season mean P conc mg/l	34	33	-	46	22	35	-	
Early season P loss, kg/ha	52	17	-	0	12	87	-	
Main season mean P conc mg/l	35	28	46	42	25	24	55	
Main season P loss, kg/ha	244	8	138	0	62	270	171	
Total NO$_3$-N loss, kg/ha	1891	281	1002	0 (2)	817	5423	477	
Total P loss, kg/ha	296	25	138	0 (2)	74	357	171	

(1) Based on theoretical water requirement; no water consumption data (2) Assumes no leaks (for details see text)

even during the main season, had an estimated annual loss of over 5,500 kg N/ha. No tomato growers in the survey actually analysed the run-off from the slabs, as opposed to the slab solution. However results from HRI Efford (Fussell and Hand, 1994; HDC Project PC 55a) showed that the nitrate-N concentration in the run-off was greater than the applied concentration for most of the season (Fig 9.1) The difference between the applied and run-off concentrations varied from *c.*0 to 165 mg/l N. Interestingly, run-off was still higher in N than the applied solution for about 70% of the season, even for the 65 mg/l applied N treatment. Grower No 6 had an average applied N of 337 mg/l N early season and 227 mg/l N main season. Even assuming that the N concentration in the run-off was the same as in the applied feed the total N losses for the season would be 3,400 kg N/ha. Grower No 2 could not give separate water use figures for the pepper crop. In Table 9.6 water consumption figures from Neinhuis and Vernoij (1990) have been used, together with actual nitrate and phosphorus figures. Estimated losses from this rockwool system, recirculated from mid-February, are the lowest in the survey with the exception of NFT.

Use of chlorides

Grower No 1 had a high run-off value (55%) compared to the cucumber growers, but limited the annual nitrate-N loss to 1.9 t/ha by using potassium chloride. Since the survey was completed, many more tomato growers have begun to use chlorides. HDC-funded work at Efford has shown that crops can be grown with applied nitrate levels of 65 mg/l N without a reduction in yield or serious quality defects, (Section 8.2). One reason for the popularity of chloride-based feeds is the considerable financial savings which can be made (*c.*£2,700 per ha). There is also the potential for modifying the balance of sweetness, acidity and saltiness components to achieve a tastier tomato by adjusting conductivity, potassium and sodium chloride levels in the nutrient solution (Marks, 1991).

Results from experiments at PTG Naaldwijk (Sonneveld and Van der Burg, 1991) indicated a tendency toward specific sensitivity to sodium chloride for cucumber and a higher incidence of blossom-end rot in peppers grown with sodium chloride compared to those grown at the same EC with conventional feeds. Work is in progress at HRI Efford and Stockbridge House to look at the effect of chloride and low N feeds on peppers (funded by MAFF).

In the 1993/94 season tomato growers using chloride are generally aiming for 200-250 mg/l N in the early season and 125-150 mg/l N main season. The amount of nitrogen lost from a run-to-waste system depends on both the volume of run-off and the nitrogen concentration. The consequences of this on nitrogen losses at various run-off levels are shown in Table 9.7, adapted from a table produced by Marks (1993 pers. comm). The values in Table 9.6 are only approximate because as stated above, the nitrogen concentration in the run-off is often higher than the applied value and the difference between applied and run-off N concentrations may well be dependant on the percentage run-off. To achieve N losses similar to arable crops and field vegetables it would be necessary to have an applied N level of 125 mg/l or less and a run-off percentage of 10% (Table 9.7). Even the best irrigation systems cannot deliver better than 10% variability when new. Therefore the use of chlorides would appear to be a short-term solution if the industry has to limit its nitrate losses to levels achievable in field crops.

Nitrate losses comparisons

Nitrate leaching is a natural process, but losses from "extensive" land uses such as pine forest or unfertilised grass are very low: less than 10 kg N/ha/year. Losses from arable crops and field vegetables are usually less than 100 kg N/ha (Table 6.1).

Clearly, losses of nitrate-N from hydroponic systems are excessive when compared to those from arable crops. Even losses from most arable situations would result in drainage exceeding the EC limit of 11.3 mg/l NO_3-N in most eastern areas of England. The nitrogen applied to hydroponic crops is also greatly in excess of the crop requirement (Table 8.25). In agricultural systems, losses take place chiefly over winter, when fertiliser is not applied. For glasshouse situations, losses may take place throughout the year. There is a risk of large losses at times when the input from other agricultural sources is small.

Nitrate-N losses from run-to-waste hydroponic systems are similar to those from fields which have been used as "sacrifice" areas to dispose of slurry from intensive livestock units over a number of years. This practice contravenes the Code of Good Agricultural Practice for the Protection of Water (MAFF, 1991). The Code requires that application rates should be adjusted so that the supply of plant nutrients does not exceed crop requirements. The Code also recommends a maximum application rate of 250 kg/ha for organic manures although lower limits may be appropriate in Nitrate Vulnerable Zones. The EC Nitrate Directive (see Section 2) will ultimately limit application rates for organic manures to 170 kg N/ha within designated Nitrate Vulnerable Zones unless an objective case for higher rates can be sustained (Pain and Smith, 1993). Losses from hydroponic nurseries can be put into context by comparison with other intensive land uses such as pig production. For example, there are approximately 866,000 people and 774,324 pigs in North and South Humberside combined. They excrete approximately 5,196 and 5,813 tonnes of nitrogen per year, respectively. The run-off from the run-to-waste hydroponic crops in Humberside only amounts to between 2 and 3% of the figure for people or pigs. This would not be a significant proportion if it were spread evenly over the whole area, but the glass is concentrated in only a few small areas. The environmental impact may be serious at catchment level.

Nitrate-N losses from glasshouse (or container HONS) units may be diffuse or "point-source". If the excess solution drains into the soil and passes down through the subsoil and underlying strata until it reaches the water table then it represents a diffuse loss. If the nursery has a functioning underdrainage system which discharges to a ditch or watercourse then this constitute a "point-source" of nitrate-N. The importance of point source inputs of solution with high nitrate-N concentration will depend on many factors which include:

- the volume of water being discharged.
- the background N level in the watercourse.
- the volume of water in the surface waters.

High point source inputs will particularly cause a problem when river discharges are low and the point of entry of the pollution is close to an abstraction point (Harris, 1991). According to Harris, horticultural discharge may become the dominant N source in some surface waters in the summer months (Section 3.14).

UK situation compared to Holland

The agriculture and horticulture industry in Holland is relatively more important to its national economy than that of the UK (Section 7). The glasshouse industry is four times larger than that of the UK and highly concentrated. This has resulted in severe surface water pollution in certain areas. The Dutch growers are faced with the same EC Directives as apply in the UK, plus a considerable amount of domestic legislation. With many growers in Holland facing financial difficulties due to poor returns there is limited scope for investment to reduce environmental problems. Relatively few Dutch growers use recirculating hydroponic systems at present, perhaps as little as 5%, although the target is for 80% of glasshouse vegetable production to be grown in closed circulation hydroponic systems by 1995. Growers appear to be waiting until they are forced to recirculate or for financial assistance in the form of grants. It seems likely that if Dutch growers are forced to recirculate they will lobby for similar standards throughout the EC so that they are not placed at a disadvantage or that they will use their "environmentally friendly" growing system to gain a marketing edge. The following is a quotation from Muilerman, the water quality project co-ordinator for the South-Holland Environment Federation (in Oosterhout, 1991).

> "It has been our experience that growers are looking for clarification of the regulations. As far as the emission of nutrients is concerned, recirculation is a feasible option both from a technical and business economics point of view. The average nursery can easily cope with the level of investment required. The government should therefore set a deadline for the compulsory introduction of recirculation for each crop. Failing this intervention, growers will keep wavering when it comes to investing in the environment, particularly while other investments bring in better returns. Giving them instructions will nicely help them over the threshold."
>
> "The federation takes the view, moreover, that there are also economic benefits to be gained from environmentally friendly growing practices. More and more often, consumers are asking for a produce which has been grown without harming the environment. If the Dutch grower takes the lead over his foreign competitors in this context, then what now appears to be a burden may eventually turn out to be a competitive advantage."

Recirculation costs

As discussed above (see Table 9.6) using chlorides to reduce the applied N level to 200 mg/l early season and 125 mg/l main season coupled with a run-off of 30% would result in a nitrate loss of 415.5 kg N/ha. This is at least four times the loss from arable and vegetable crops (Table 6.1) and may well still be unacceptable within Nitrate Vulnerable Zones or to the NRA if discharged to controlled waters (see Section 2). HDC-funded R&D at HRI Efford indicates that further reductions in NO_3-N can be made without any detrimental effects on crop yield and quality. However only NFT and recirculating systems can truly be said to reduce nitrate and pesticide loss to a minimum. The poor returns for salad crops over the past few years mean that growers are unlikely to be able to afford the capital costs of installing recirculating systems. It is very difficult to obtain accurate costs, but estimates are given in Tables 9.8 (a) and 9.8 (b). It is assumed that yields are the same for both systems and that the greenhouse is laser-levelled so that troughs are not required for NFT. There is no allowance for solution sterilisation. Many growers in the UK have grown tomatoes successfully in NFT for years, without sterilisation. However, a few growers have experienced problems with root diseases (eg Clover, 1992). For a review of sterilisation methods see O'Neill (1992). According to

Table 9.8(a) Cost of conversion from run-to-waste rockwool to a "low-cost" NFT System (per ha)

Debits		**Credits**	
Extra variable costs	per year	**Costs saved**	per year
polythene for channels	1820	rockwool slabs (1)	4250
additional electricity	1500	labour (2)	2077
		fertilisers (3)	3740
		water (4)	3290
			13357
Capital costs (5)			
Laser levelling			
polystyrene base			
return gulley, plumbing			
circulating pumps			
catchment tank	19390		
Total debits	£22,710	Total credits	£13,357

Table 9.8 (b) Cost of conversion from run-to-waste rockwool to recirculating rockwool system (per ha)

Debits		**Credits**	
Extra variable costs		**Costs saved**	
additional electricity	750	fertilisers	3740
		water	3290
	750		7030

Capital costs			
Plumbing for run-off collection, holding-tank, pump	5,540		
Total debits	£6,290	Total credits	£7,030

Net gain £740

Notes

(1) rockwool slabs steamed, rebagged and reused for a second season.

(2) laying out slabs 1st year, re-using 2nd year, removing slabs at the end of the 2nd year.

(3) based on a grower using chloride fertilisers.

(4) based on mains water @ £0.47 per m^3.

(5) capital costs amortised 5 years at 12%.

(6) no allowance for solution sterilisation.

(7) assumed that both systems have equal yield potential.

Nienhuis (1990), the total fixed plus variable costs of a pasteurisation system with a capacity of 2.5 m^3/hour (sufficient for 1 ha of glass) is D fl 12,700 per year. Disinfection of water from an NFT system would be very expensive due to the large volumes of solution involved. Also disinfection in an NFT system offers no protection to plants downstream of a diseased plant because pathogen propagules may contaminate roots of downstream plants as water flows to the collection tank for disinfection (0'Neill, 1992).

In Holland there is great interest in the search for the ideal closed cultivation system because of the requirements of the MYCPP (see Section 7). One study compared 36 systems (Dings, 1991). Those with trays and collection of drainage in one collecting pipe to each two rows of plants (eg Libra tray from Beekenkamp) or to each row (RC tray from Revaho) had quite high investment costs. However, if it was assumed that rockwool slabs can be steamed and re-used for seven years then on an annualised basis the Revaho system was the cheapest closed system (Dfl 4.71 l/m^2, approximately £1.69 at date of writing), closely followed by the Libra tray system. (All costs include disinfection by pasteurisation). Another promising system is the Agribeek from Agrimatic. This is a small "wing-trough" which is buried in a trench and lies directly under each row of plants, underneath the plastic sheeting. It can be combined with either wrapped rockwool slabs or trays. For V-systems drainage "sections" have been developed which are used with wrapped slabs. The slabs drain into a trough which sits in a section. The trough discharges into one central collecting drain per row of plants. Dings classifies NFT along with root-spraying (aeroponics) as "revolutionary systems". NFT is not favoured because the large volume of solution is expensive to disinfect. All systems gave a net loss compared with the traditional run-to-waste system, after allowing for savings in water and fertiliser.

A very large project at PTG Naaldwijk is examining economic and operational aspects of recirculating systems in great detail. (Nienhuis, 1990). In this study the system with the lowest capital cost in which drainage water could be collected cost over Dfl 7/m^2. In this method, known as a "trunking system", several rockwool slabs are sleeved together. The slabs are sloped and overwrapped. The drainage water is not kept separate from the roots and the system often has leaks which are not easy to find. Systems using troughs and pipes where the run-off does not come into contact with roots of plants further along the line cost Dfl 11-14/m^2 (exchange rate 31.3.94 £1 = 2.79 Dfl).

In terms of annual costs (taking into account depreciation, interest, maintenance, labour, fertilisers, water, electricity, disposal and costs of re-using rockwool) the V-system plus channel gave the lowest annual cost, better than the traditional method using rockwool for three years. However, the permanent systems are depreciated over 7-10 years and some growers feel that due to rapid developments and uncertainty in the future, that five years should be the maximum depreciation time (Dings, 1992).

Thus it can be seen that the costs involved in converting from a run-to-waste system to NFT cannot be recovered over a five year period in terms of savings in rockwool slabs, labour, fertilisers and water. There is a slight advantage in converting from run-to-waste to recirculating rockwool, but this does not include the cost of solution sterilisation and the small net gain would soon be wiped out by any root problem which could occur. However, the maximum penalty for causing pollution of a watercourse is £20,000 in the Magistrates Court and an unlimited fine in the Crown Court. It may also be necessary to pay for any damage caused by the pollution (eg fish killed or clean-up costs). As far as the author knows, no grower has yet been prosecuted for allowing run-off from a run-to-waste hydroponic system to pollute controlled waters, but it would be advisable to include assessment of the pollution risk in any calculations of the costs of converting to a closed system.

Alternatives to recirculation

Given that capital costs of recirculating systems are high, what other options are available to growers for disposing of run-off?

There is potential for growers in eastern England, the Vale of Evesham and on the South Coast to use the run-off from hydroponic crops to irrigate outdoor crops such as potatoes, sugar beet and vegetables (Section 8.1). Whether this is feasible will depend on the close proximity of suitable crops, since the fertiliser value is too low to make transportation worthwhile. Grass intensively cut for silage has a large nitrogen requirement; the main dairy regions however are situated in areas of high rainfall, away from most glasshouses.

Another alternative is to pass the excess run-off through a reedbed. This approach is being tested at HRI Stockbridge House, with funding from the HDC. To date, the system has not been successful in significantly reducing the nitrate. The bed at Stockbridge House has been specially constructed and the reeds are growing in a layer of gravel. This type of bed has been successful in reducing BOD (Biological Oxygen Demand) and to a lesser extent ammonium-N (Hope, 1993). Other types of reed bed with organic substrates have been used to reduce phosphorus. One problem is that the conditions to reduce one pollutant may be the opposite of those required to reduce another. Some reedbeds have been managed with variable water levels. Reedbeds are a promising area but further development work is needed.

At the Guernsey Horticultural Advisory Station, a pilot scheme was able to remove about 90% of the nitrate from solution fed into specially designed ponds. Around 20% of the nitrate-nitrogen was absorbed by aquatic plants, the remainder was denitrified by anaerobic bacteria (Anon, 1989).

Another possibility is short rotation coppice (SRC) using fast growing species such as poplar and willows. The crop can be harvested every 2-5 years as woodchip that can be burnt to produce heat and power. These species have the potential to transpire a lot of water. The roots form a network below the soil surface which could be effective in removing nutrients. Some work has already been undertaken on the yield benefits of applying sewage sludge to SRC. Arable energy coppice is a renewable energy source which is `carbon neutral' and energy efficient.

Grants are available for establishment. The Non-Fossil Fuel Obligation (NFFO) requires Powergen to buy the power created by renewable resources at premium prices but present growers are mostly considering using the chipwood for their own heat and power needs.

10. CONCLUSIONS

10. CONCLUSIONS

1. Discharges from horticultural point sources such as nurseries growing hydroponic crops on run-to-waste systems could become the dominant source of nitrate in some surface waters during the summer months when inputs from other agricultural sources are small. (Harris, 1991).

2. The three pesticide active ingredients approved for application to the root zone of hydroponics crops (carbendazim, etridiazole and propamocarb hydrochloride) appear unlikely to pose a serious pollution problem when used correctly. Studies are required to determine the actual losses to soil occurring.

3. Soil mineral nitrogen values after rockwool and soil-grown tomatoes and cucumbers were much greater than those found in most other agricultural and horticultural soils, exceeding 71,000 kg N/ha at some sites. The *potential* for loss of nitrate-N is extremely high if the soil is leached after a succession of rockwool or soil-grown crops.

4. A detailed analysis of seven nurseries covering tomatoes, cucumbers and peppers and three production systems (run-to-waste rockwool, recirculated rockwool and NFT) showed losses equivalent to 477-3,400 kg N/ha and 138-357 kg P/ha from the run-to-waste crops.

5. Results from the case studies showed that the minimum run-off achievable in practice is *c.*30%. Any run-off in excess of this is increasing pollution and adding to the growers' costs. Water applications by some growers were 50-60% in excess of theoretical crop requirement.

6. Lack of accuracy in irrigation is a major constraint to reducing nitrate losses. This is due to variability in output between drippers and differences in evapotranspiration between plants. More sophisticated methods of triggering irrigation may match crop needs more closely but irrigation equipment must be able to deliver precise amounts.

7. The HDC-funded chloride experiments have focused attention on to nutrient budgets and have identified that current run-to-waste rockwool systems are very wasteful of nutrients.

8. The use of chloride fertilisers has potential to reduce considerably nitrate losses from run-to-waste hydroponic systems. However, using chlorides to reduce the applied N level to 200

mg/l early season and 125 mg/l main season would still result in a nitrate loss of approximately 415 kg N/ha, given a run-off of 30%. This is at least four times greater than the loss from arable and outdoor vegetable crops.

9. Chlorides offer a good interim measure but ultimately leaching losses can only be reduced to levels compatible with the Nitrate Directive by converting to NFT or recirculating systems or by finding acceptable uses for waste solution.

10. Recirculating systems can result in savings of 30-50% in water use and at least 50% in fertilisers. However, if capital costs are spread over five years and all other costs are taken into account, it does not pay to convert to NFT. There may be a slight net gain in converting to a recirculating rockwool system, but not if the cost of solution sterilisation is included.

11. There is potential for growers in eastern England, the Vale of Evesham, and on the South Coast to use the run-off from hydroponic systems for outdoor irrigation but whether this is feasible depends on the close proximity of suitable crops.

11. RECOMMENDATIONS

Table 9.7 Estimated N losses for a range of applied N and run-off values (kg N/ha/year).

Feed volume (l/m^2)	**700**	**780**	**875**	**1000**	**1200**	**1400**	**1750**
Run-off %	**Nil**	**10**	**20**	**30**	**40**	**50**	**60**
N conc mg/l							
50	0	40	88	150	250	350	525
75	0	60	131	225	375	525	788
100	0	80	175	300	500	700	1050
125	0	100	219	375	625	875	1313
150	0	120	263	450	750	1010	1575
175	0	140	306	525	875	1225	1838
200	0	160	350	600	1000	1400	2100
225	0	180	394	675	1125	1575	2363
250	0	200	438	750	1250	1750	2625
275	0	220	481	825	1375	1925	2888
300	0	240	525	900	1500	2100	3150

NRA	National Rivers Authority
NSA	Nitrate Sensitive Area
Pathogen	an organism which can cause disease.
Pesticide	any fungicide, herbicide or insecticide or related product (excluding medicines) used for the control of pests or diseases
Slurry	animal waste in a liquid form
Surface water	water from rivers, impounding reservoirs or other surface water source
µg/l	microgram per litre (1 µ g = 0.001 mg)
Water source	an individual abstraction of water from a river, lake, reservoir, spring or an aquifer for treatment at a treatment works. Some treatment works receive water from more than one source.
Water supply	water leaving a treatment works. (A treatment works is a place where raw water is treated prior to supply through the distribution system to consumers.
Water supply zone	the basic unit of supply for establishing sampling frequencies, compliance with standards and information to be made publicly available; defined in the regulations as an area in which not more than 50,000 people are estimated to reside.

11. RECOMMENDATIONS

1. Growers should be made aware of the large amounts of nutrients that are being lost from run-to-waste rockwool solutions. Apart from the pollution risk, financial losses of up to £6000/ha are occurring.

2. Growers with piped underdrainage systems discharging rockwool run-off to "controlled waters" should be made aware that they risk fines of up to £20,000 in a Magistrates Court or an unlimited fine in the Crown Court plus damages (unless they hold a discharge consent). They should be encouraged to analyse solution from drain outfalls and to recognise signs of eutrophication.

3. Results from the HDC-funded irrigation trials (PC 23C and PC82), along with practical experience from the case studies in this report, should be used to produce a blue-print for minimising run-off as well as maximising yield and fruit quality.

4. R&D is required comparing existing designs of irrigation equipment including nozzle type, nozzle output and ways of reducing variability.

5. Further R&D is required to look for totally new methods of triggering and applying irrigation with greater accuracy and to take account of the variation in evapotranspiration between plants.

6. The HDC-funded work on reduced nitrate input for tomatoes and the MAFF-funded work comparing a reduced nitrate treatment with a standard feed for peppers should be expanded to include a nitrogen response trial for both peppers and cucumbers.

7. All nutrition, irrigation and recirculation trials should include sufficient monitoring for nutrient balances to be calculated. This must include accurate water use figures, run-off volumes and analyses. The yield response of a crop will be influenced by irrigation amount as well as N concentration, particularly for low applied N treatments (Section 8.2).

8. This report focuses on nitrogen and, to a lesser extent, phosphorus. All other nutrients are potentially being applied in excess and strategies are needed to reduce losses (assuming no general move towards recirculation).

9. An attempt should be made to measure N losses by denitrification under glasshouse conditions.

10. Studies should be made of the actual pesticide losses occurring to the soil following applications to the root zone.

11. Work on recirculation and sterilisation techniques should be given high priority as leaching losses cannot be reduced to levels compatible with the Nitrate Directive by use of chlorides unless run-off can be reduced to below 10%. This is not possible with present irrigation technology. There is an urgent need for effective, low-cost disinfection plus recirculation techniques.

12. Work on biological treatment of run-off should be expanded to include different designs of reedbed with organic substrates and short-rotation coppice using the woodchip produced as a renewable energy source.

13. The Dutch are directing large resources into a programme of research to examine the economic and operational aspects of working systems with lower environmental impact in glasshouse horticulture. It is essential to keep abreast of developments in Holland by all means including study tours, conferences, literature reviews and personal contacts.

14. Converting from run-to-waste rockwool to NFT or recirculating systems does not appear to be cost-effective, especially if disinfection is included. It is essential for the industry to be aware of grants, tax incentives or any other financial aids available to growers in other EC member states and to lobby effectively for equal treatment.

15. A review is needed of the environmental impact of the pot and bedding plant industry.

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Storage of Data

The raw data from Sections 4 and 5 will be stored by the ADAS Horticulture Business Centre at Chequers Court, Huntingdon, Cambs, PE18 6LT and at subsequent locations for a period of ten years. The HDC will be consulted before disposal.

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