cafre
College of Agriculture,
Food & Rural Enterprise

HYDROPONIC PRODUCTION OF LEAFY SALADS AND HERBS

Mark Huey
Horticulture Technologist
Greenmount Campus, CAFRE
Mark.Huey@daera-ni.gov.uk

DAERA
Department of Agriculture,
Environment and Rural Affairs
www.daera-ni.gov.uk

Contents

1. Introduction

Plants rely on soils to provide them with both physical support and as a reservoir of water and nutrients. However, growing crops in fields creates challenges such as weeds, soil borne diseases, crop contamination and damage from poor weather conditions – which has encouraged growers to grow plants under protection in combination with hydroponic production techniques.

Hydroponic (or ‘working water’) culture is the production of plants without using soil as the growing medium, instead the roots grow in substrates such as peat or rockwool (substrate culture), or directly in water (water culture). In both substrate and water culture hydroponic systems, the plants are initially grown as a ‘plug’ plant (Figure 1) where the seed is sown into a small volume of substrate and grown on until the seedling is large enough to be moved to production area. Since plants are grown without soil in nutrient rich water, hydroponics is also described in literature as soilless cultivation or nutriculture.

Figure 1. Lettuce seedlings grown in rockwool cubes

Although substantial amounts of salad crops were produced using hydroponic techniques by the US Army on Pacific islands in WWII in order to shorten the supply chain, the commercial domestic production of crops started in earnest from the 1960’s. The factors that drove this rapid growth included the introduction of cheap, mouldable plastic and the massive growth in production of inexpensive and reliable artificial fertilisers. By combining hydroponic production techniques with protected structures (e.g. glasshouses and polytunnels), the grower was able to finely tune the environment (e.g. air temperature, humidity) and optimise the supply of nutrients increasing plant growth.

Furthermore, the adoption of hydroponic production enable growers to operate in areas where the quality and type of soil, such as heavy clay, would make normal soil production challenging. By growing indoors growers can also limit losses from pests and diseases, improve uniformity and boost yields. Since the move from soil grown tomatoes to hydroponic production systems, yields have increased by 25%, and similar increases have been recorded for a wide range of crops. Currently Netherlands has 4,600 ha under hydroponic cultivation in greenhouses, mainly tomatoes, cucumbers and strawberries, with companies in UK investing heavily in new greenhouse using hydroponic production techniques. Thanet Earth, a 90 hectare greenhouse now produces ~10% of the UK’s tomatoes, cucumbers and pepper all produced hydroponically.

One major division in hydroponic systems is determined by fate of the nutrient rich water supplied to the plants (Figure 2). One type of production system is the ‘run to waste’ or ‘open’ approach where the water is allowed to drain away into a tank or into the soil after the plants have been irrigated, with a fresh solution applied at every irrigation. This approach enables a very simple approach to be taken to managing the nutrient supply, but this practice wastes a lot of fertiliser and can lead to pollution of the groundwater if water is not retained after irrigation.

In contrast, in a 'closed system' the irrigation water is collected in a tank and is then recycled back to the plants – minimising the quantity of nutrients and water lost to the environment. However, due to the activity of the plants absorbing and excreting different nutrients and chemicals in closed systems the pH (relative acidity of the solution), electrical conductivity (EC, which indicates the quantity of fertiliser), and dissolved oxygen (DO) levels can fluctuate rapidly. These factors therefore need to be tracked on a daily basis to ensure they are within defined limits otherwise plant growth will be affected. Since closed systems will minimise nutrient loss to the wider environment UK growers are now encouraged to install closed systems, and in the Netherlands open systems where the excess nutrient solution drains into the soil have been banned since the late 1990's.

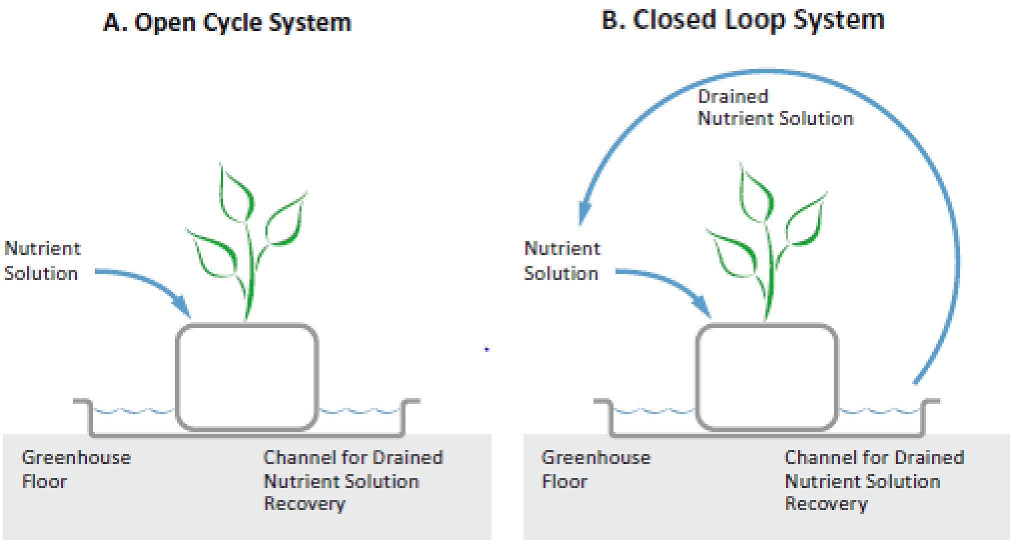


Figure 2. Fate of irrigation water in an open and closed hydroponic systems.

2. Hydroponic systems

As stated in the introduction, hydroponic systems can be categorised as being either a 'water' or 'substrate' culture. Although in both approaches seedlings are initially grown in a small portion of growing media for the first 3 – 4 weeks, in water culture after planting the roots of the plants are suspended in water or along a stream of water. In contrast, in substrate culture the roots of the plants will grow into a substrate or growing media into which the seedling has been planted. Water culture tends to suits leafy, fast growing plants like leafy salads and herbs, with substrate culture used to grow long term crops like cucumbers, peppers and tomatoes.

2.1 DWC (deep water culture)

This is a very simple and low cost hydroponic production system based around a pond of water (10cm to 30cm in depth) with a pump that circulates the water to maintain uniform DO levels. Polystyrene slabs with holes drilled in them are placed on the surface of the water, into which seedlings are placed (usually rockwool cubes) and the roots then grow in the water (Figure 3). Due to the large volume of water in DWC's in relation to the quantity of plants grown in them, the speed of changes in pH and EC levels (see nutrient solution management) tend to be slower than other approaches. However, unless mechanisation is integrated into the system labour costs tend to be higher than other production systems. In addition the large volume of water that needs to be periodically disposed of can be a challenge as it contain large amounts of fertilisers which poses a pollution risk to the environment. The system does lend itself to a 'loop' or conveyor production system, with young plants on a tray being fed into pond at one end, and mature plants taken off ready for harvest at the other end (Figure 4).

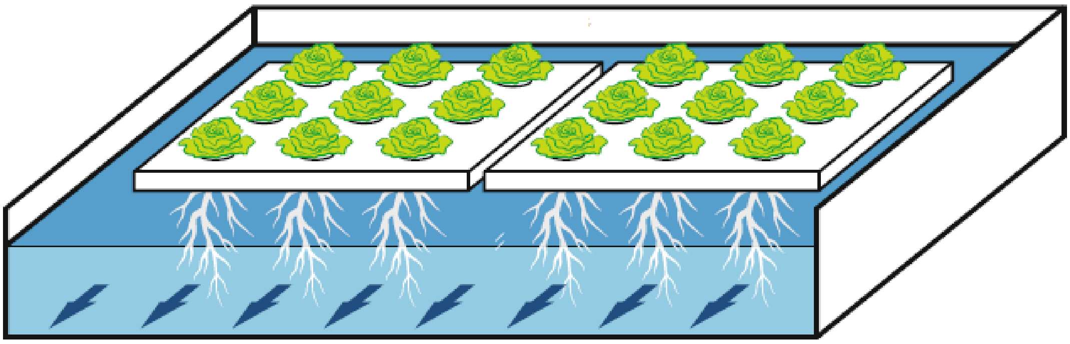


Figure 3. Cross section diagram of a DWC system showing floating polystyrene trays in pond of water

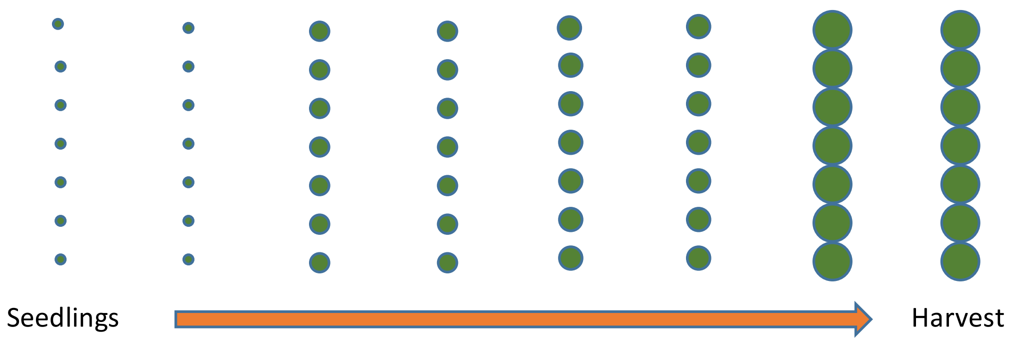


Figure 4. Conveyer production approach in DWC

One of the most critical aspects in operating a DWC is maintaining DO levels, since if these drop below 4ppm plant growth can be affected, and this extra stress plants experience can make them more prone to infections. Since the water surface in DWC is covered by slabs, this limits direct diffusion of oxygen into the water and means that growers have to pump oxygen into the water. This can be achieved by agitating the water, an air stone or a Venturi system which is T shaped joint that draws air into the water stream as water flows through it.

Figure 5 and 6. Airstone and Venturi valave used to increasse aeration in hydroponic systems

2.2 NFT (nutrient film technique)

The NFT system was heavily promoted by Dr. Cooper in the 1970's and became the main hydroponic production system in many greenhouses, and was widely used to grow tomatoes and cucumbers. The NFT system is normally based around plastic channels which may have detachable lids, along which a thin (1 – 3mm) layer of water flows along its length pumped into the channels at ~ 1 to 2 litres a minute (Figure 7) from a reservoir tank.

The channels are installed to create a slope from where the water enters the channels to the point it exits (normally a 1 to 5% fall) to create this flow of water. Seedling are placed in holes in the channel and the roots then grow along the base of the channel. This turned out to be the major weakness in using NFT to grow long term crops like tomatoes, as the roots eventually clogged the channels stopping the even flow of water. In addition, since the volume of water that ran along the channels was so small, if the runs were long (>15m) the plants at the end often suffered nutrient deficiencies and lower growth from the low oxygen levels in the water.

However, the system is ideal for short term crops like lettuce, and as long as the length of the channels is not greater than ~15 metres, issues such as nutrient deficiencies are not a problem. However, since 99% of the internal space in NFT troughs is air, the temperature will respond very quickly to external air temperatures – and if they reach high enough temperatures it can kill the roots. Secondly, since the volume of water is small, it can heat up quickly as it flows along the channel, and as water heats, the oxygen dissolved in the water drops rapidly. If oxygen levels drop below 4mg/litre, plant growth is affected. Thankfully, given our temperate climate this should only present a problem in summer, but is worth being aware about.

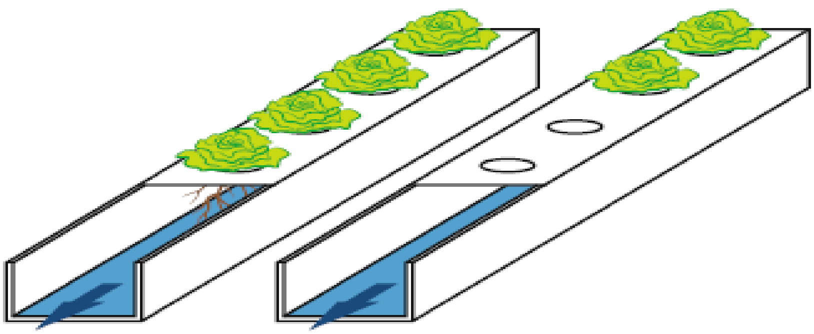


Figure 7 NFT troughs

2.3 Aeroponics

This is one of the technologically advanced hydroponic production techniques using either high pressure pumps (>90 psi) with fine nozzles or ultrasonic atomisers to generate exceptionally small (0.02mm – 0.05mm) droplets of water. These ultra-fine water droplets create a fog around the plant roots from which they can absorb nutrients (Figure 8), along with a high level of aeration that supporters claim produces exceptional plant growth. Much work in this technique is being carried out by NASA since it takes very little water to run the system, and this would enable astronauts to grow food on a potential journey to Mars where water resources would be extremely limited. However, it little used in commercial settings since if the pump breaks, there is no reservoir of water available to the plants and they can start wilting within minutes. Secondly, due to fine nozzles the irrigation water has to be extremely well filtered to prevent blockages, and accumulated salts from the fertiliser's solution can clog nozzles and stop atomisers from working.

Most aeroponic systems available to the small/amateur growers are actually based around a low pressure pump (2 – 3psi) and standard irrigation nozzles. These produce much larger droplets (>0.5mm) which do not hang in the air, and as the roots expand they can obstruct the spray from the nozzles leading to dry areas and uneven/poor growth. As a results these low pressure systems cannot sustain the same levels of growth recorded in high pressure systems.

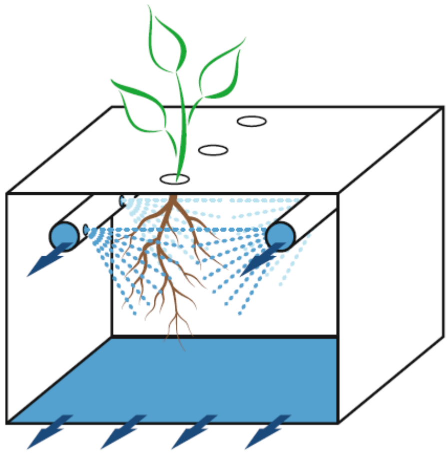


Figure 8 Cross section of aeroponic system

2.4 Substrate culture

In substrate culture, the roots grow in an inert organic or inorganic substrate such as peat or rockwool in a container. The substrate can then act as a reservoir of nutrients and provide buffering against swings in pH and EC levels in the irrigation water. The substrate also provides more anchorage and space for roots to grows, so larger and longer term crops can be grown, such as tomatoes (Figure 9). There are two major methods to irrigate the plants when in the container (Figure 10) – drip irrigation or ebb and flood (E&F). In drip irrigation the water is applied at the surface of container via drippers or sprinklers, and flows down through the substrate until it drains out where the leachate is collected for recycling or disposal. In contrast, with E&F water floods the floor or table on which the pot rests to 2 – 3cm in depth for 10 – 15 minutes, with capillary action drawing water up into the container. At the end of the flooding cycle, water is drawn away from the table/floor and returned to the reservoir.

Figure 9. Tomatoes grown in slabs of rockwool irrigated by drippers

Source: Goldlocki, https://commons.wikimedia.org/wiki/File:Tomato_P5260299b.jpg

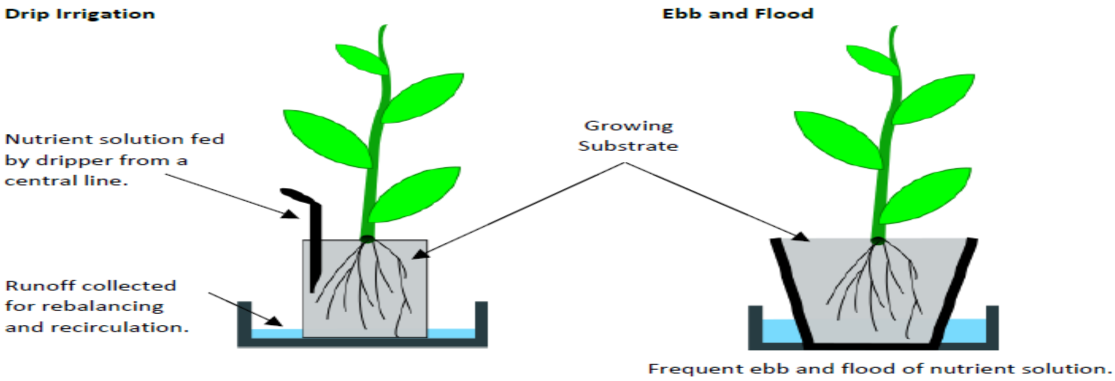


Figure 10 Substrate irrigation with drip and E&F irrigation

2.6 Choice of substrates

Peat has been the substrate of choice in horticulture for 40+ years, as it offers a superb blend of physical and chemical characteristics. However, its extraction from peat bogs is highly damaging to the environment, and growers are coming under increasing pressure to move towards reduced peat or peat free substrates to grow their crops.

Peat reduced and peat free blends

Typically growers will use a mix of materials, such as perlite, bark chippings, wood fibre to achieve at least a 25% reduction in use of peat. These blends take considerable expertise to manufacture to ensure they do not affect plant growth, and growers can buy pre-blended mixes to suit the needs of a range of plants.

Peat Free (coir alone)

This is material generated form the external husk of coconuts, and offers similar physical attributes to peat, and can retain more nutrient than rockwool and is a very popular hydroponic substrate. However, since coconuts grow near beaches, the coir can have high levels of sodium and potassium, and growers should only buy buffered coir which has been treated to reduce the levels of these salts.

Rockwool

Rockwool is produced by heating basalt until it is molten and spun to form a candyfloss type of material, which can then be made into cubes, slabs and granules, It cannot retain nutrients (has a low CEC), but drains easily and has a high degree of aeration and is a superb propagation material. It cannot be reused, and disposal can present a problem but the manufacturer have recycling program set up to turn waste rockwool into rockwool bricks for building.

Oasis

Oasis is a phenolic foam and is an inert material with similar physical properties to rockwool, but tends to be more friable and can easily break apart, and works better when used in propagation. Like rockwool there are issues over fact it cannot be recycled and is non-biodegradable.

3. Nutrients

The process of nutrient management and absorption is critical to management of a hydroponic system, since plant can only absorb nutrients that have been dissolved in the water by the grower, or are present in the raw water supply. Depending on the academic source, there are between 14 and 16 what are termed essential plant nutrients, with some debate over whether silicon and chlorine should be considered a plant nutrient. Nutrients can be divided into two groups depending on the relative quantity required by the plant (Figure 11). The exact quantity of nutrients can vary between crops, for instance fruiting crops like tomatoes and cucumber, requiring a much higher level of potassium in their feed compared to leafy greens. The amount of fertiliser in solution is often stated in units of parts per million (ppm) which is equivalent to mg/litre –so 200 ppm N is same as 200mg N/litre of water.

Macro Elements			**Micro elements**		
Element	**Symbol**	**Plant available forms and charge**	**Element**	**Symbol**	**Plant available forms and charge**
Nitrogen	N	NH_4^-, NO_3^+	Iron	Fe	Fe^{2+}, Fe^{3+}
Phosphorous	P	PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$	Manganese	Mn	Mn^{2+}
Potassium	K	K^+	Boron	B	$B(OH)_3$ no charge
Calcium	Ca	Ca^{2+}	Copper	Cu	Cu^+, Cu^{2+}
Magnesium	Mg	Mg^{2+}	Zinc	Zn	Zn^{2+}
Sulphur	S	SO_4^{2-}	Molybdenum	Mo	MoO_4^{2-}
			Sodium	Na	Na^+
			Chloride	Cl	Cl^-
			Silicon	Si	$Si(OH)_4$ no charge

Figure 11 – Range of essential macro and micro nutrients required by plants, form absorbed by plants and their relative charge

Over the years, a vast range of ‘recipes’ have been developed, but some growers still use the Hoagland recipe that was initially developed in 1950 with consistently good results. Growers can either create their own recipes from what are termed straights – these are fertiliser salts that contain at least one, but more commonly two nutrients (see Appendix 1). By blending and dissolving different proportions of these straights, a grower can tailor the nutrients to meet the exact needs of their crops, and make minor adjustments to nutrient recipe throughout the growing cycle. However, working out quantities requires involves some lengthy calculations called cascade calculations, which can be daunting for inexperienced growers. However, there are Excel based nutrient calculators which will calculate the quantity of fertiliser required for each stock tank based on water quality, intended recipe, dilution rate and size of stock tank or growers cans seek advice from FACTS trained advisors.

A better option for new growers is to at least start with blends created by professional fertiliser companies that contain practically all the nutrients required. Downside of this approach is the range of recipes available is much more limited (i.e. the ratios of N, P an K are ‘fixed’), and is a much less flexible approach to delivering plant nutrients, and still requires additional calcium nitrate to be added to the water since calcium is absent or present at low levels in most of the mixes (due to precipitation if used in stock tanks – see below in Figure 12). Finally, many hydroponic shops supply fertiliser in the form of premixed liquid solutions, which are simple to use – but are an expensive option.

To get the fertiliser into the irrigation water the grower has two options – they can dissolve the fertiliser directly in the reservoir or holding tank, but downside of this approach is it is time consuming making up a fresh batch every time the tank is emptied. Instead, in commercial nurseries the fertilisers are then dissolved to form highly concentrated ‘stock’ solutions, which are then diluted (usually between 1:50 to 1:200 dilution ratio) to create the solution in a mixing tank that is then applied to the plants. This approach means there is no need for a large holding tank which contains the final feed solution, plus it allows growers to make changes to the feed solution if required.

However, if certain nutrients are combined under these high concentrations in the stock tanks, such as calcium and sulphate, they can combine to form an insoluble compound that settles at the bottom of the tank – a process termed precipitation. For this reason growers separate fertiliser that will precipitate into two separate stock tanks – Tank A and Tank B, with an additional tank with acid to control pH in the water. If using straights, potassium nitrate is split between tanks A and B since it has low solubility (does not dissolve easily) and splitting quantities between tanks ensures all of it dissolves. If using a blended fertiliser this would be dissolved in one tank, with the calcium nitrate in the other. This approach is normally combined with an automatic dosing system, which tracks changes in EC and pH, and injects the correct amount of fertiliser or acid to correct levels (Figure 13).

Tank A	**Tank B**	**Tank C**
Calcium nitrate	½ Potassium nitrate	Acids
½ Potassium nitrate	Potassium sulphate	• Sulphuric
Iron chelate	Monopotassium phosphate	• Nitric
	Magnesium sulphate	• Phosphoric
	Mono ammonium phosphate	• Citric
	Ammonium nitrate	
	Micronutrients	

Figure 12. Typical division of fertilisers and acids in 3 tank system

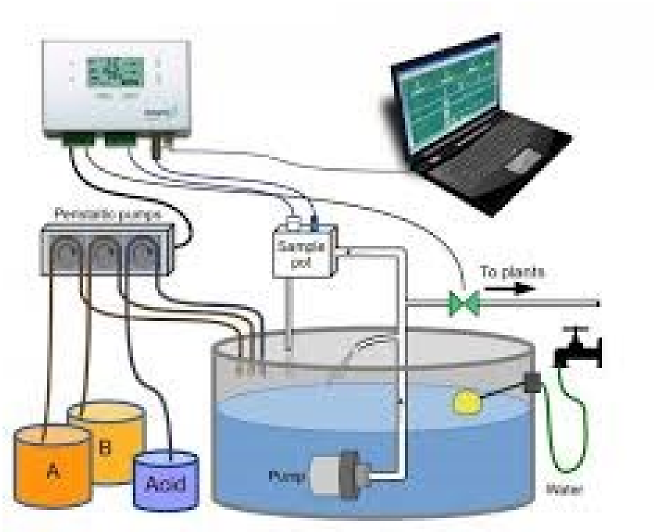


Figure 13. Schematic of an auto-dose system

3.1 pH

pH is a measurement of the acidity or alkalinity of a solution, and is dependent upon the relative quantities of hydrogen ions (H^+) and hydroxyl ions (OH^-), and runs on a scale of 1 – 14 (Figure 14). If there are more H^+ ions than OH^- ions, the solution is acidic (less than pH 7) and if there are more OH^- than H^+ ions the solution is alkaline (more than pH 7). This is one of the most important measurements to track in hydroponic production as the pH of a solution affects the solubility and availability of nutrients to plants. In some studies up to 50% of plant nutritional disorders can be tracked back to issues with the pH environment. If pH gets too high or too low, some nutrients will become too soluble and poison the plant (phytotoxicity) or will not be available to the plant causing nutrient deficiencies.

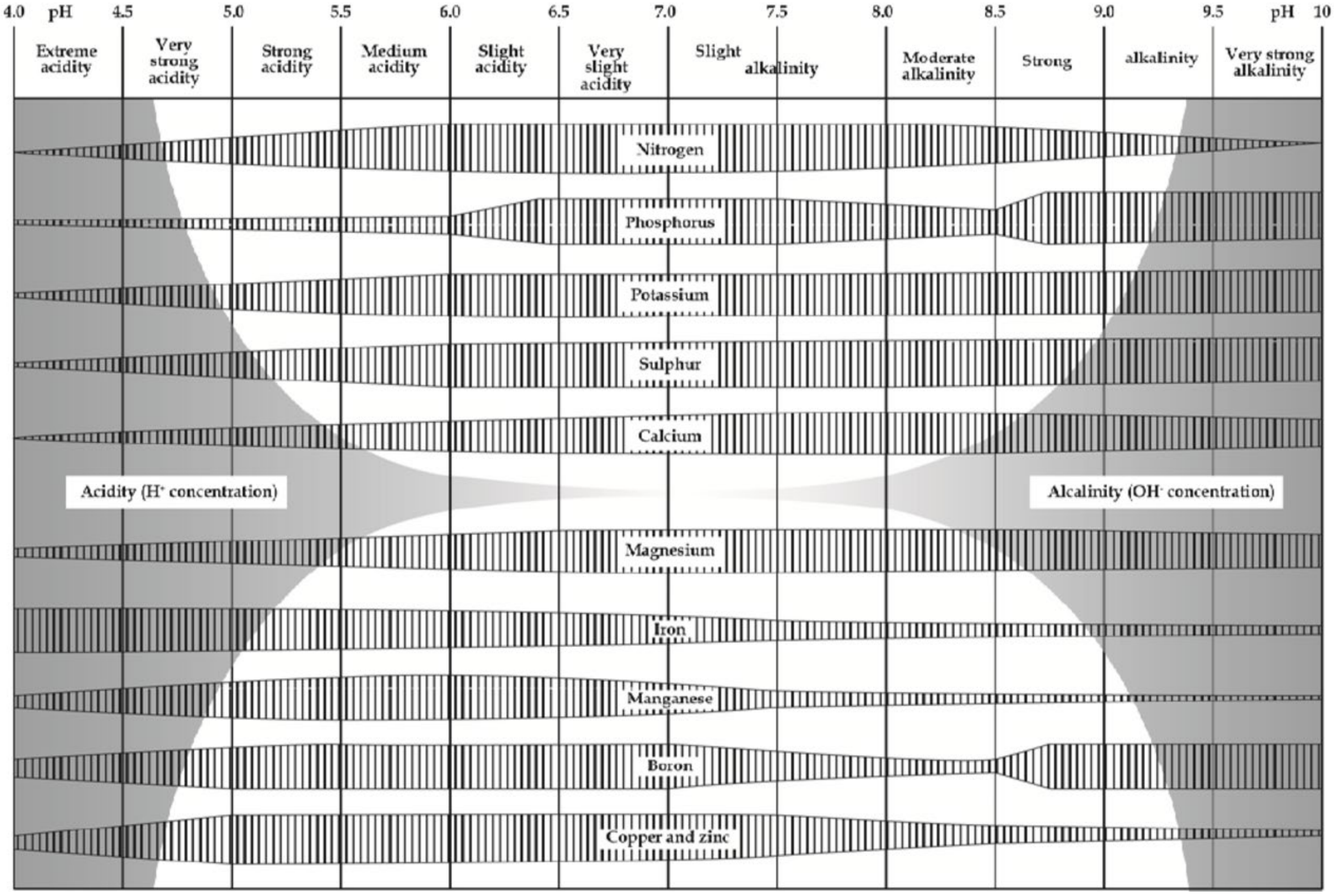


Figure 14. Troug's diagram showing solubility of different nutrients across range of pH environments. Each nutrient is represented with a band; the thickness is proportional to the availability.

3.2 Electrocoductivity - EC

When a fertiliser dissolves in water, it breaks down into positively ions (cations) and negatively charged ions (anions) such as potassium with a positive charge, K^+, and nitrate with a negative charge NO_3^-. As the quantity of these ions increases in the water, the ability of water to transmit electricity increases raising the electrical conductivity (EC) of the water. This is a useful measure of the *total* amount of fertiliser present, and it is usually measured in units of micro Siemens per cm (mS/cm). If excess fertiliser is added to the nutrient solution, or the water quality is poor the EC levels can rise to dangerous levels, affecting plant growth through osmotic stress (plants can't absorb water), accumulation of toxic ions (such as sodium and chlorine) and nutrient antagonisms. EC can also be expressed in units of dS/M (deci Siemens per metre) and µS/cm (micro Siemens per cm). Conversion factors to swap between readings are: 1000 µS/cm = 1 mS/cm = 1 dS/m. Growers can buy EC 'pens' for £60 that will allow them to track changes in EC, but there are other pens that will measure both pH and EC which can be bought for ~£150 and are available form a range of manufacturers. Regardless of the type of pen you have, it is critical that they are calibrated on a regular basis, preferably weekly, as the readings can 'drift' over time.

EC will not provide a guide to levels of individual macro and micro nutrients in the irrigation water, for this a sample needs to be sent a professional lab for analysis. However, plants will grow better under certain concentrations of nutrient solution, so growers are recommend to group plants according to their preferences for EC, and if growing a range, the grower should use an EC to have a lower EC rather than a higher value, as excessively high EC's can cause wilting, root tip dieback and leaf necrosis.

3.3 Dissolved oxygen

All portions of the plants carry out respiration, using sugars and oxygen to create energy and releasing carbon dioxide and in plant roots this energy is used to absorb nutrients from water. Therefore if the oxygen levels drop below certain levels, respiration is inhibited in the roots and plant cannot effectively absorb nutrients resulting in nutrient deficiencies. The design of the hydroponic system can have a great impact on levels of oxygen experienced by the plants, with an NFT providing high levels of oxygen to the roots since there are roots growing in the humid air inside the channel – in contrast a DWC needs to have the water oxygenated since the roots of the plants are constantly submerged in water.

Measured in mg/l or in parts per million (ppm), dissolved oxygen levels are affected by the temperature and salinity of the water, and also by other chemical and/or biological demands (COD/BOD) of the water. Cold water can hold more dissolved oxygen than warm water (see Figure 15) and fresh water can hold more dissolved oxygen than salt water.

The maximum amount of DO that the water can hold is called the saturation value. It's possible, and very often desired especially in a greenhouse to exceed the natural saturation point of DO in water, called super-saturation. At levels around 5 mg/l of dissolved oxygen, irrigation water is typically considered marginally acceptable for plant health. Most greenhouse crops, however, will perform better with higher levels. Levels of 8 mg/l or higher are generally considered to be good for greenhouse production. In addition to affecting plant growth, if plants are exposed to low oxygen levels in the water, the risk of an infection from a root pathogen *Pythium* increases rapidly, so achieving good oxygenation of the water is essential.

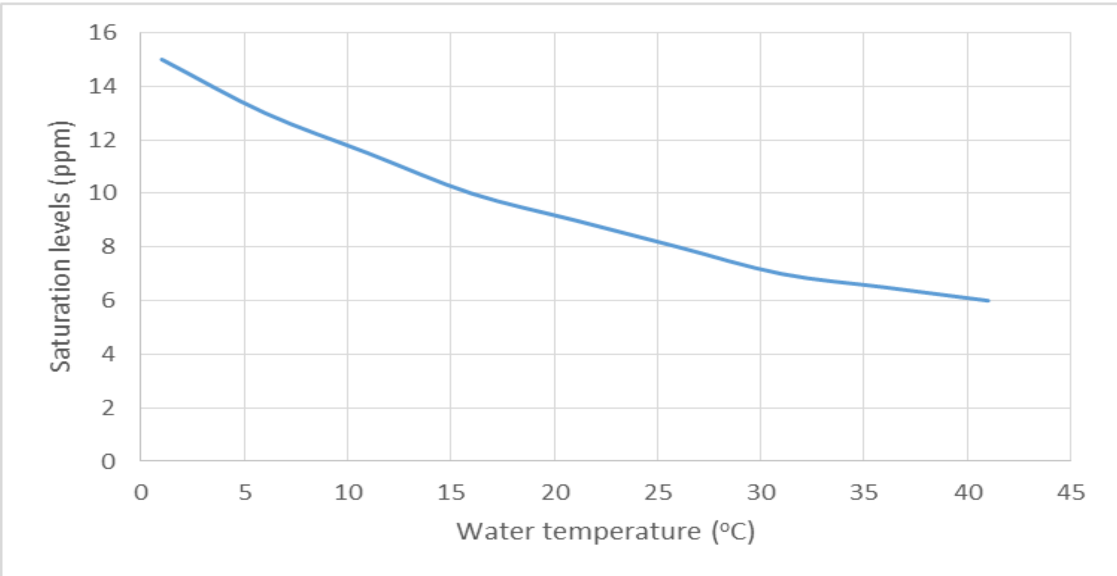


Figure 15. Graph showing drop in oxygen saturation levels with increasing water temperature

4. Water quality

We are lucky in Ni than the majority (~99%) of our water supply is generated from surface water in upland areas, which means is has relatively few impurities in in. This is very important in hydroponic systems, especially in closed systems where the quality of water can determine the success or failure of a hydroponic facility. The most important parameters in relation to water quality are as follows.

4.1 Electrocoductivity

In addition, as water passes through rocks it can pick up a range of soluble chemicals that will contribute to the EC of the water, and when the fertiliser is then dissolved in the water the EC will increase even further. As a result, the EC for raw water used in hydroponic production is ideally around 0.75mS/cm and should never exceed 1.5mS/cm. If a new water source is being considered (such as a borehole), a sample should be sent for analysis before it is used to identify potential problems. If the EC is very high options include blending with rainwater to lower EC, or using 'reverse osmosis' equipment which lowers the concentration of salts in solution.

4.2 Biological contamination

Mains water in NI is rigorously treated to ensure no bacteria that can affect human health, such are *E. coli* are eradicated before entering the water system. However, if a borehole water is used, it should be sent to a lab on a regular basis to ensure human pathogens are present. This is less of an issue if the borehole is sunk into the bedrock, but wells which draw water directly from the soil profile can be contaminated. Since leafy greens and herbs are sold as fresh produce, if the water used to irrigate the plants is contaminated, this poses a high risk of contaminating the crop.

4.3 Filtration and sterilisation

Filtration can play two roles within hydroponics – to remove particulate matter that can block irrigation pipes/pumps, and biological filtration which can help minimise risk from water borne plant pathogens. Particulate matter can be removed by installing inline 'Y filters' that filter the water as it exits the pump (figure 17). These need to be cleaned on a weekly basis by stopping the pump and removing the mesh from the filter, or back flushing where the water flow is revered and used to propel the residue out thorough a valve on the filter.

Figure 16 Images of Y filter used to remove particulate matter from water

In closed systems there is a high risk of a root infection spreading very quickly across the entire cropping area that shares the same reservoir. The main plant pathogens that affect plants in hydroponics are the Oomycetes, *Pythium* and *Phytophthora*, which can devastate a crop if plants are stressed (e.g. nutritional delicences, high temperatures) and their levels reach critical levels in the water. In biological filtration, water is trickled down through fine particles in a tank, and over time a biologically active layer develops in top 10cm of the particles called the 'schmutzdecke'. This layer contains bacteria that can attack and destroy oomycetes in the water. Practically all biological filters use sand, and are mostly called slow sand filters (SSF) – see Figure 17.

General recommendations are the entire volume of water in the reservoir should pass through the SSF in 24hrs, with a SSF with a surface area of 1m3 capable of treating 4000 litres in 24hrs. The maximum flow rate to gain disease control is ~300 litres/hour. Growers can make 'drum' SSFs from 200 litre containers with simple plumbing equipment to work with up reservoirs of ~1000 litres, but large scale units are better constructed by professional greenhouses construction firms.

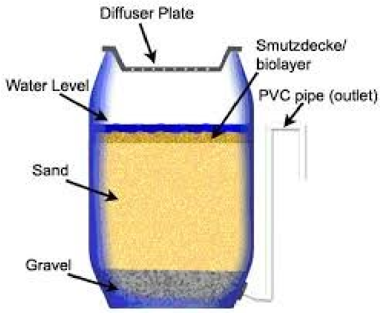


Figure 17 Simple SSF based around 200 litre plastic drum

There are other options to control oomycetes in water such as UV light, chlorination and ozonation. Chlorination and ozonation are technically challenging, potentially dangerous and can highly expensive techniques to use, and are not suitable for small growers. Low powered UV lights on the other hand can be integrated into irrigation systems, treating the water as it exits the filter. This location is vital as solids in the water will interfere with the action of the UV light (breaks up DNA/RNA in the pathogens) so water must be reasonably clear. It is also critical to match the flow rate to the power of the lamp used, as the dose rate (the energy transmitted in the water) must be at 250 joules/cm^2. Anyone seeking to install a lamp should seek advice from the manufacturers to ensure this criteria is met. One final point is, although UV light will kill pathogens, it can also destroy chelated iron in the water, increasing chances of iron deficiency arising in the crops.

4.4 pH and alkalinity

pH will affect the plants ability to absorb nutrients, so needs to be carefully monitored and adjusted on a regular basis using acids, but the quantity required will be dictated by the alkalinity of the water. Alkalinity is also termed the 'acid buffering capacity' - the ability of water to neutralize acids. In the UK it is measured in mg/litre of carbonates, $CaCO_3$, and bicarbonate, Ca $(HCO_3)_2$, and in good quality of water these should not exceed 100ppm.

High levels of carbonates can cause problems with clogging of irrigation lines or nutrient imbalances if levels exceed 150ppm. The aim of acidification is not to remove all the carbonates, otherwise there is no buffering in the water and pH levels can then fluctuate wildly – should aim to leave ~60ppm bicarbonate in the water.

Acids used to lower pH include the mineral acids sulphuric acid, nitric acid and phosphorous acid and organic acids such as citric acid. The use of concentrated mineral acids requires specialised equipment and protective equipment, as they are caustic agents posing high risk to skin and eyes, especially nitric acid. In addition, since phosphoric acid and nitric acid will increase levels of phosphorous and nitrogen in the nutrient supply, their use needs to be included in any nutrient budgets calculated for the crops. Citric acid is the safest to use, but is not a strong acid therefore greater quantities need to be used compared to any of the mineral acids

5. Crops

5.1 Lettuce

Although standard lettuce is a commodity crop (high volumes/ low profit margins) there is potential to develop niche markets based on unusual or rare lettuce not available in a typical grocery store. Lettuce is an ideal crop for hydroponic production due to their fast turns and rapid growth in these systems, but due to the long cropping time, iceberg lettuce is not a suited to hydroponic production. Lettuce can be harvested whole, or if a loose leave variety is grown multiple harvests can be taken off the same plant.

Figure 18 Lollo rosso, buttehead and cos lettuce varieties

5.2 Chard

Chard or Swiss chard (*Beta vulgaris*) is related to the beet family, and is a large, leafy green which is like spinach has a high concentration of vitamins. Both the leaves and stems of chard are edible, with the colourful stems making it attractive product when bundled. It lends itself to niche marketing as the large fleshy leaves do not have a long shelf life and are best retailed via a local market like a farmers market. An advantage to growing chard rather than spinach as a leafy green product is chard tends to be more resistant to *Pythium* infections which can destroy a spinach crop.

Figure 19. Stems of chard

5.3 Kale

Kale, *Brassica oleracea L.* is another 'nutrient dense' leafy green like chard and spinach, and comes in a range of leaf colours and forms. Kale, which is a non-heading cabbage, is like chard is a cool season crop, with high temperatures causing off flavours in the leaf. It can be harvested whole at maturity, or treated as a CCA crop, taking ~30% of the leaves at each harvest. There are 3 main types of kale, deeply curled 'Scotch' kale, 'cavolo nero' kale with dark almost black leaves, and Siberian kale with smoother leaves which has the mildest taste of all the kale types. The major challenge with growing kale is the thick and robust stem that develops over time

Figure 20 Different forms leaves of kale available to growers

5.4 Mustard greens

Mustard green leaves, *Brassica juncea* add heat and flavour to salad mixes and sandwiches, with a huge range of leaf colours and shapes available. However, under hot conditions, they are prone to start flowering (bolting) which can affect the taste of the leaves. It should be treated as a CCA crop, with ~30% leaves harvested at any one time.

Figure 21 & 22 Mustard greens come in wide range of leaf shapes and colour

5.5 Asian greens

There is a broad category of plants which are used in Chinese and Japanese cuisine. Bok choi, also called Chinese cabbage (*Brassica chinensis*) is one of the common Asian greens seen in supermarkets, and its thick, sweet stems can be steamed or fried. Growers should buy compact, F1 varieties as older varieties can become excessively tall. Other popular Asian greens include Mizuna (*Brassica japonica*) which produces mild, finely dissected leaves. This can be treated as a CCA crop, and is a useful filler in salad mixes. Due to its size (~30cm wide at maturity) it will need wider spacing compared to most other crops (~30cm). Other crops that could be considered are Shungiku (*Chrysanthemum coronarium*) also known as chop suey or chrysanthemum greens. It should be harvested young (10 – 20cm in height), and treated as a CCA crop, where shoots can be harvested every seven days under good growing conditions.

Figure 23, 24 & 25, From right to left, pak choi, purple mizuna, chop suey greens

Although looking at EC/pH/temperature recommendations there does appear to be some overlap between conditions required for leafy greens and herbs, they will perform under a more herb specific nutrient mix, but can be grown with a leafy green nutrient mix. They can be spaced at anything from 12 – 20cm spacing depending on crop type and harvesting options, but in general follow the same spacing used to grow crops in the soil.

5.6 Basil

Basil is an herb that benefits from local production as the intensity of the flavour diminishes within a few hours of picking, and varieties vary in both taste and appearance. The most popular variety is the sweet or Genovese basil, but there may be markets for lemon, Thai or spicy basil cultivars. It can be one of the most challenging crops to grow as it is prone to downy mildew but it can be a highly attractive product. To maximise production, you need to prune plant to encourage development of side shoots which can then be harvested at roughly 3 week intervals. Unlike many other products, basil should not be refrigerated or held below 12ºC or leaves will blacken and loose flavour. Basil is a light demanding crop, and without use of supplementary lighting it will be hard to start crop any earlier than April in UK.

Figure 26. Basil Genovese

5.7 Oregano

Another popular culinary herb, the two main varieties are Greek (*Origanum vulgare*) and Italian (*Origanum x majoricum*). The Greek has smaller, fuzzier leaves and the Italian has larger leaves with perhaps a stronger scent and flavour. It’s considered a woody herb, and as such takes longer to mature, but when mature the tips can be harvested every 3 to 5 weeks. Because of the longer cropping time, it may not offer as good returns as other crops.

Figure 27. Greek and Italian oregano

5.8 Mint

The most common varieties are common mint (*Mentha spicata*), peppermint (*Mentha x piperata*) and garden mint (*Mentha sachalinesis*). The garden mint comes in a huge range of 'flavours' – for instance chocolate, apple, and pineapple – but choose one that will have a market. It can be produced from seed, but you can harvest plants much quicker if propagated by cuttings. Harvesting can take place when the plants are 20cm tall, cutting so there is 5 – 8cm of stem left from which the mint will regrow to harvest again in 3 – 4 weeks. Like basil it loses flavour quickly, making it a premium product for local supply.

Figure 28. Chocolate, apple and pineapple mint.

5.9 Chives

Found as common and garlic chives, both these are thin leaved alliums, with a mild onion flavour. If grown in NFT channels they are best harvested young and replanted as the root growth can obstruct the channels. They can be left in place and treated as a CCA crop, but need wider NFT channel if this production system is chosen. However, if day length is less than 14 hrs, growth can cease so if chives are to be grown year round there need to be lighting installed to extend the day length.

Figure 29 & 30. Common chives and garlic chives.

5.10 Coriander

Coriander (*Coriandum sativum*) also known as cilantro in the USA tolerates cooler temperatures than other herbs, and is sold in bunches in markets. It can be treated as a CCA crop, taking 2 – 3 harvest of the plants. The major issue with coriander is that it will bolt (flower) in summer which can cause some bitterness to develop in the leaves in mature plants. There are 'bolt resistant' varieties available that will enable growers to minimise the chances of this happening.

Figure 31. Coriander leaves

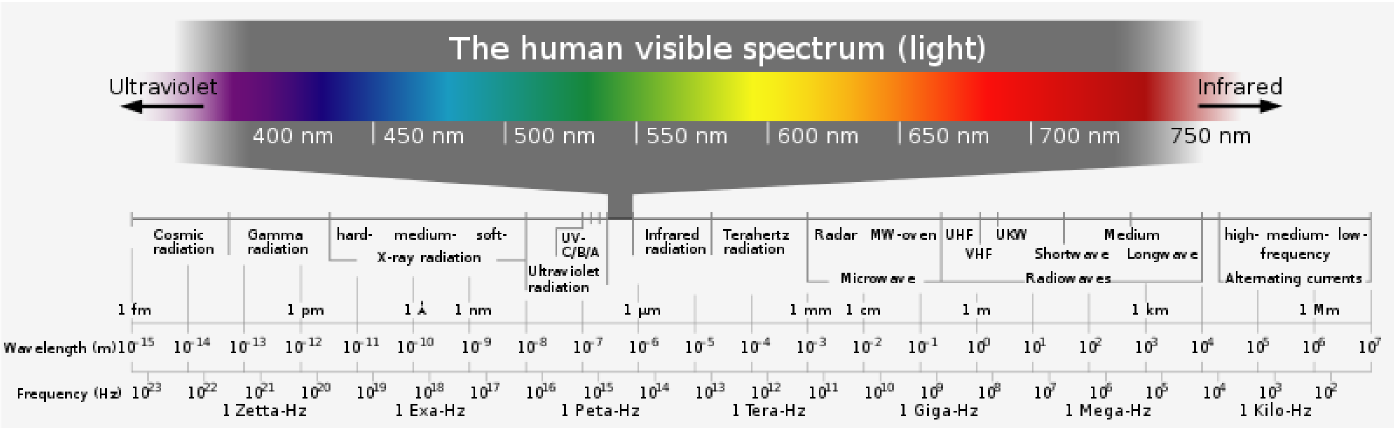
6. Environmental conditions

6.1 Light

There are three properties of light that can influence plant growth and development – quality, intensity and photoperiod.

Quality

Energy is emitted from the sun in waves of photons which vary in their wavelength, and this is termed the electromagnetic spectrum. Plants use the energy from a portion of this spectrum to drive the process of photosynthesis, where carbon dioxide in the air is absorbed by the plants and used to create sugar (glucose). This region of light used by plants is the PAR – or Photosynthetically Active Region – light, running from ~400nm (nanometres) to 700 nm, and roughly matches what the human eye can perceive as colour.



Author, Frank Horst https://commons.wikimedia.org/wiki/File:Electromagnetic_spectrum_-de.svg

Figure 32. The electromagnetic spectrum of energy produced by the sun

Not all of this light is used and absorbed by plants – the majority of the light between 500-600nm is reflected back which corresponds to the green portion of the light spectrum, and the reason plants appear green to the human eye. Maximum photosynthetic activity is seen in the blue (peaking at 450nm) and red (peaking at 660nm) region of the light spectrum (figure 35), where the light energy is trapped by pigments called chlorophyll a and b. Energy in different regions of the light spectrum is trapped by other pigments such as carotenoids which then feed the energy into the photosynthetic cycle.

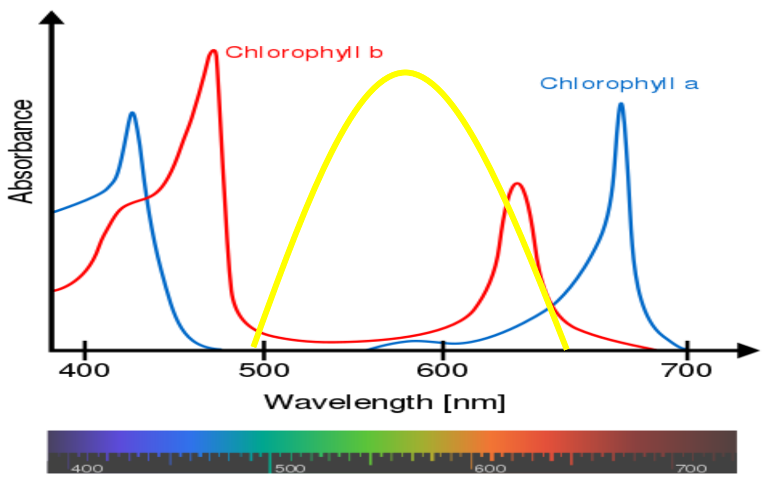


Figure 33. Graph showing relationship between absorbance of chlorophyll *a* and *b* and relative sensitivity of a human's eye to light (yellow line).

Intensity

Initial attempts to measure the 'amount' of light was based on the how bright a human eye perceives light, and this was measured in units of lumens or foot candles. Unfortunately, the human eye responds strongly to the yellow portion of the light spectrum (figure 35) – so a light source that has a high LUX reading may actually deliver very little usable light energy to the plant.

Instead a more useful unit is based on measuring the quantity of PAR light, called PPFD (photosynthetic photon flux density) and is in units of micro moles/m^2/second. It is a measure of the number of photons or light energy within the PAR (400 – 700) portion of the light spectrum falling in a defined area (m^2) in a given time (second), and provides an instantaneous measure of what useful light a plant or growing area is receiving.

Another advantage of this measurement is that if regular readings are taken throughout the day, the individual values can be 'summed' to give an indication of the total amount of light energy that plant has received. This is called the DLI (Daily Light Integral) and is measured in units of moles/m^2/day, and can be used to group plants according to the light energy required to grow quality plants – so for optimal lettuce growth you need 10 – 14 moles/m2/day, but tomatoes need 15 – 20 moles of light energy per day. This is an issue in UK, as outside light levels can plummet from autumn to spring (Figure 36), with levels dropping to around 3 moles/m2/day over the winter months. Light levels drop even further as light enters a greenhouse by transmission through the glass, glazing bars etc., so that only 50% of the light outside may reach the plants in the greenhouse.

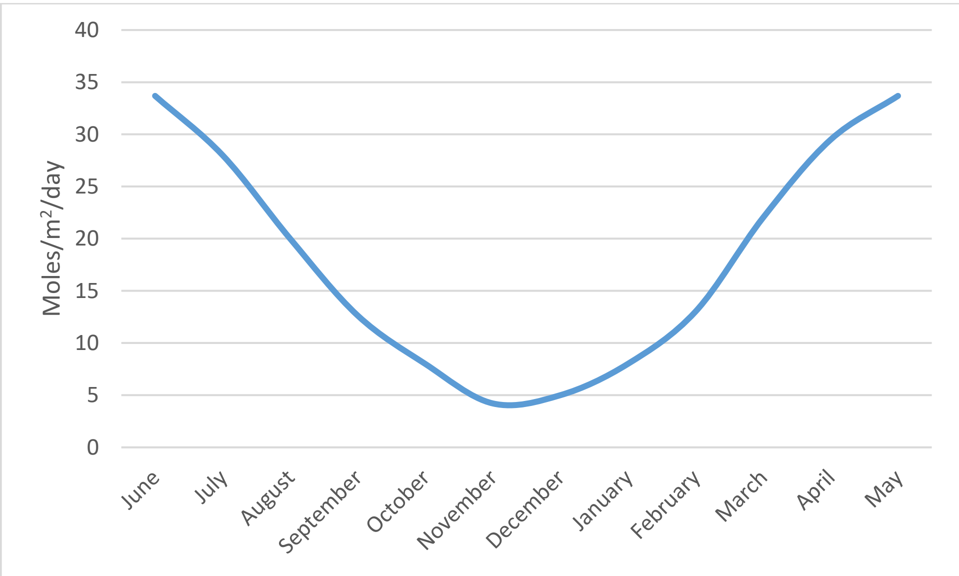


Figure 34. Graph showing changes in daily light integral (mol/m^2/day) through the year in N. Europe

If the growers then wish to maintain production, the grower the must 'supplement' the natural light in their greenhouse using horticulturally specific lighting rigs. These have been based on high intensity sodium lights for the past 40 years, but there is now a move to using LED lights which offer exceptionally long run times, and use less energy to deliver the same PAR/PPFD readings since less energy is given off by the lamps as heat compared to sodium lights. This last fact enables growers to use LEDS in vertical indoor farming, or vertical farming units, which allows grower to achieve completely closed growing rooms where every environmental parameter is controlled – but since all the light energy for growth has to come from LED lamps, the electricity costs are large.

Figure 35 & 36 Supplementary lighting in greenhouse, sodium lights on left, LED on right

Supplementary lighting is expensive, and growers need to make thorough investigation if their crop will justify the investment required to sustain growth over low light periods. Even with high return crops like tomatoes, it's not always possible to sustain a 12 month production schedule.

Photoperiod

The length of day can influence the flowering period in many plants. Since leafy green and herbs are harvested well before the flowering process can start, it is of little concern for these crops.

6.2 Temperature

All crops need a minimum temperature to grow, but grow more effectively between a certain ranges (see appendices). Some crops will grow well in cooler conditions ('cool season crops') and other demand much warmer conditions (warm season crops). By choosing plants from each category, grower can potentially supply plants all year round for different markets.

6.3 Humidity

This is a major factor in crop losses, pest and disease problems and nutrient imbalances. Humidity is a reflection of the amount of water contained in the air relative to the amount of water needed for saturated air and is expressed as relative humidity (RH). The amount of water held in air increases with air temperature, where for every 6.5°C rise, the amount of water held in the air doubles – if warm air with high RH then cools, it can reach the point the air becomes saturated, and water condenses out of the air and forms dew. The problem with this is that moisture on the plant encourages the growth of fungal pathogens that attack plants. Growers should therefore aim to keep RH levels below 80-85% to reduce disease pressure. This is normally achieved through ventilation, exchanging high RH air in greenhouse with low RH air outside. Doing so will also decrease the temperature in the greenhouse, which has to be replaced by heating (if used) where a set temperature has to be maintained. For large greenhouses (>500m^2) there is the option of investing in VLHC (Ventilated Latent Heat Converter) which uses desiccants to lower the RH in the greenhouse, and is claimed to reduce fuel costs of using the 'vent and heat' approach by ~50%.

Another benefit of lowering RH is that it encourages transpiration in plants. This is important as plants absorb calcium primarily through the transpiration stream (the movement of water from the roots and out through the leaves), and lack of calcium in lettuce causes tip burn where the edges of the leaves blacken.

6.4 Carbon dioxide (CO_2)

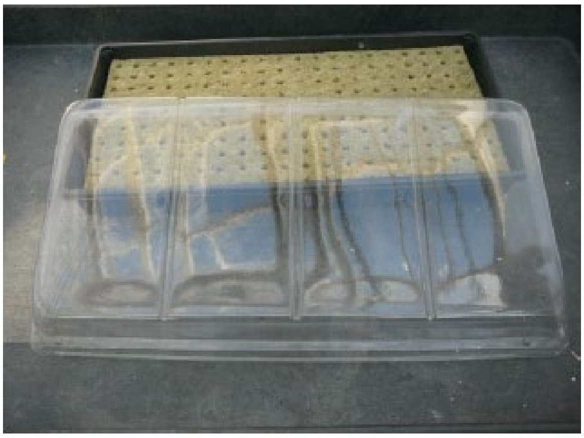
Increasing the levels of carbon dioxide in the air from 400ppm to 1500ppm increases the rate of photosynthesis and therefore yield, and has been used by growers of high value crops tomato and cucumber growers for decades. The returns generated by enriching air with carbon dioxide in leafy salads and herbs are not as marked, and carbon dioxide enrichment in lettuce production is generally limited to vertical farming systems since there is little direct exchange with outside air, and carbon dioxide levels can be quickly depleted.

7. Propagation

Seedlings can be started in a variety of substrates such as organic sources such as peat or coir, or inorganic substrates such as perlite or rockwool. The advantage of using rockwool cubes is that it will not break up in hydroponic systems and cause blockages in the piping, but rockwool must be conditioned before use. This involves submerging the cubes in mildly acidified water (no less than pH 5.5) to lower the pH of the rockwool cube which has a ~pH8.0 after manufacture since lime is used in its manufacture.

Further advice on this process can be obtained from the manufactures online resources. Other good pre-formed propagation materials include Oasis cubes (used by florists) or glue plugs. Glue plugs are composed of a range of growing media such a coir bound together by a glue so the plug does not break up during use.

Seed should be sourced from a reliable supplier, and where possible using clay coated seed where seed are encased in a thin layer of clay, which dissolves in contact with water. This process allows faster sowing (especially of small seed), and minimises loses when using expensive F1 seed. After sowing and gentle watering, the material should be placed in a germination chamber. This is an enclosed area where the temperature and humidity is controlled. Much more even and higher germination rates will be achieved if a stable temperature (~20^{o}C) can be maintained over 24hrs, and if the humidity is kept around 95% RH, as high humidity allows the seed to rapidly absorb water to start the germination process. Units that hold multiple trays can be easily constructed, but if working with a small number of trays using a humidity dome with an electric heating mat will work.



Figures 37 & 38 Image of simple multi-layered germination chamber, and seeding tray with humidity dome

Seedlings should not be immediately transferred to the production area for two reasons. Firstly they should be irrigated with a lower strength feed solution (~50% of the main production feed) until roots mature otherwise initial growth after germination can be slowed. Secondly, growing seedlings in a propagation area at high densities maximises the production space available in the chosen hydroponic system. As the seedling mature in the propagation area, the strength of the feeding solution should be increased until it matches that used in the productions area. Failure to let the seedling adjust to the stronger feed can lead to transplant shock where the growth is slowed until that adjustment is made by the plant. If possible, irrigation should be from below to minimise disease risks and can be done by placing plants on trays or benches where drainage can be controlled. (Figure 38)

Figure 39. Lettuce seedling propagated in trays with sub-irrigation

8. Pests and disease

Although the control of soil borne diseases is a major advantage of hydroponic production that does not mean hydroponic production systems are free from diseases. Instead, the nature of the pathogen has changed, and water borne pathogens such as *Pythium* and *Phytopthora* can badly affect crops. These pathogens are Oomycetes, and thrive in hydroponic systems if control measures are not put in place. Many of the plant pests that affect soil grown crops will also affects hydroponic crops – such as aphids and whitefly.

To control pest's grower should implement an IPM system, Integrated Pest Management where the emphasis in on prevention and use of biologicals controls, with the use of pesticides as a last resort. When you have to spray is dictated by the pest 'threshold' – which is the point at which not spraying will be more expensive than applying a spray.

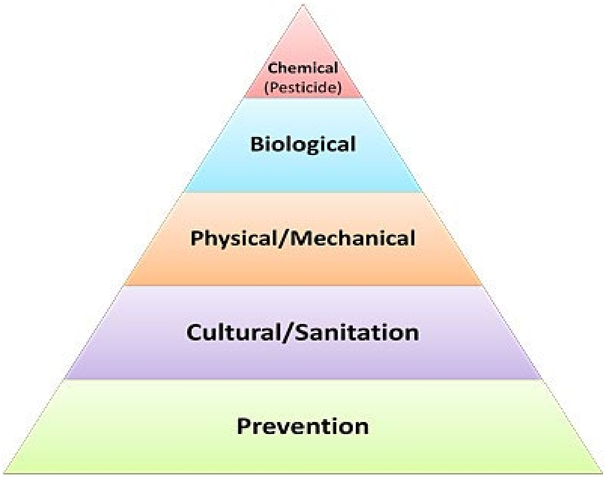


Figure 40. Typical IPM triangle

The overall concept is often set out as an IPM triangle, with use of conventional pesticides as the last option to be implemented.

Prevention

This can be as simple as not introducing diseased plants into the greenhouse, so always check propagation material from an external company, or your own material from disease before planting. Select varieties with resistance against certain diseases (e.g. Basil 'Nufar' is more resistant to mildew infections),

Cultural/sanitation

Clean down production areas with suitable biocides, remove all plant trash from site, clean harvesting tools between each use, and restrict access to site to essential workers. Good air circulation will reduce humidity around the cop canopy, so consider use of HAF (Horizontal Air Flow) or vertical fans to mix air in a greenhouse. Implement a good scouting program to give early warning of potential programs. Weeds can act as hosts for a range of pests and diseases, so keep areas outside structures free of weeds.

Physical/Mechanical

Use mesh on door (and possibly vents) to exclude flying insects, sticky traps for monitoring and reducing pest numbers – these should be checked on a twice weekly basis as part of the scouting program.

Biological

There has been a huge increase in using natural predators of many pests to control populations. A number of companies will advise and supply the correct type and number of predators to control pests in your greenhouse.

Chemicals

Chemicals (or pesticides) can be divided into two groups – bio rational and conventional. Bio rational pesticides are pesticides that relatively causes no harm to humans or animals, and do little or no damage to the environment. They can be based on bacteria, viruses, fungi or protozoa, plant extracts or chemical analogues of naturally occurring biochemical (pheromones, insect growth regulators, etc.). Bio rational products should be used first before using a conventional pesticide which may pose a higher risk to human health and the environment. The exact pesticide that can legally be used varies with crop and location, so professional advice must be sought from BASIS trained advisors before anything is applied.

8.1 Aphids

These are sap sucking insects and can damage plant not only by extracting the sap, but by injecting toxins and virus into the plants, and their presence should be monitored using yellow stick traps as they affect practically all leafy salads and their presence can affect their marketability.

Figure 41. Aphid on lettuce leaf

In a protected environment like a greenhouse, biological controls (predators the eat pests) offer very good control for aphids. Advice should be sought from suppliers who will recommend the best predators and release rates for your particular situation. The use of pesticides is highly restricted on fresh produce, and advice should be sought from a BASIS trained advisor before any product is applied.

8.2 Powdery mildew

This fungal disease appears as white spots mostly on the upper leave surface, with older leaves being affected first on mature plants and lettuce are particularly susceptible. Leaves become pale, twisted and growth is slowed with severe infections killing the plant. Certain environmental conditions such as dense foliage, warm temperatures (18 to 25^{o}C), and high humidity (95% RH) create the perfect combination for mildew to grow.

Figure 42. Powdery mildew on lettuce

Since lettuce are high risk crop, substantial amount of breeding has gone on to develop resistance varieties, so growers should select these varieties to grow. Ventilation and air movement will reduce RH and temperature, and good scouting will catch disease at early stages before it can spread to rest of crop. There are range of pesticides (bio rational and conventional) that will offer some control, but advice should be sought from a BASIS trained advisor.

8.3 Downy mildew

Basil is prone to this disease caused by the fungus-like organism *Peronospora belbaharii*, with the green leaved varieties such as Genovese particularly so. Initial symptoms are leaf curling, followed by a grey growth on the underside of the leaf. It can be carried on seed, in the air or by insects and thrives in warm, humid conditions.

Figure 43. Downy mildew on basil

Like lettuce, best option for growers is to use a resistant cultivar (some of the coloured and Asian varieties show some resistance) along with good hygiene practices and reducing RH in the growing environment.

8.4 Botrytis

Otherwise known as grey mould affects many plants, but lettuce is particularly susceptible. The disease thrives in high humidity, with masses of spores released from infected plant material which spreads the infection elsewhere.

Figure 44. Botrytis on lettuce

Breeding for botrytis resistant lettuce is ongoing, but no commercial varieties have been released as yet. Instead growers, like other fungal disease must maintain good hygiene and scouting practices, removing infected plants at the first sign of the diseases. Ventilation and decreasing RH will also decrease disease pressure from botrytis.

8.5 Pythium

Along with *Phytopthora*, *Pythium* belong to a fungi-like group of organisms the Oomycetes. These organisms can produce mobile spores than increase the rate of distribution in hydroponic systems, and if infection occurs root growth is affected, affecting crop yield.

Figure 45. *Pythium* infection of lettuce roots and impact on yield

Once it builds up the critical levels in a hydroponic system it can devastates a crop, so limiting its growth through good sanitation and cultural practices is essential. This starts with ensuring seedlings were propagated in a *Pythium* free environment, removing all organic material and treating equipment with a suitable biocide between crop cycles, and maintaining good levels of sanitation with cropping equipment. Levels of *Pythium* in the water can also be minimised using combination of SSF's and UV light to destroy *Pythium* as it circulates through the water. Pythium is an opportunistic pathogen, so will generally only attack a plant if it is under stress (nutritional, oxygen levels etc.)

For this reason growers should ensure environmental conditions do not increase risk of infection. This can include proper nutrition levels (EC and pH) and ensuring oxygen levels do not drop below 5ppm. Fungus gnats that feed on algae can transfers the disease between sites, so good insect control will minimise this risk.

9. Harvesting

When a plant is harvested, the process of respiration continues using sugars and oxygen in leaf tissue and producing heat and carbon dioxide. The depletion of sugars in the plant tissue can affect taste and texture, so limiting respiration is vitally important. Since oxygen is a key driver in the process limiting the quantity in around the plant tissue will reduce respiration. Large growers supplying supermarkets achieve this using specialised chambers where the can reduce oxygen levels from 21% to 3%, but these are unsuitable for small produces. For small quantities of produce, getting the produce into airtight packaging is best option for cut produce, such as 'clamshell' packaging (Figure 48). Lowering temperature will also reduce respiration rates, so growers should have a suitably sized cooler to take 'field heat' out of the crop. However, not all crops will tolerate the low temperatures (0-3^{o}C) normally used in storage chambers. Basil for instance will blacken if stored at this temperature, and should not be exposed to temperature lower than 12^{o}C. Storage times in the cooler can vary between crops, but most leafy greens can tolerate up to 2 – 3 weeks in a cooler. Growers can limit the amount of heat which is in the plant tissue by harvesting in the early morning and the evening, and limit additional physical damage which can accelerate respiration by using sharp scissors, smooth edges harvesting containers and adequate training in proper harvesting technique.

Figure 46. Lettuce in clamshell marketing tray.

Preventing microbial contamination with human pathogens is critical, and advice should be sought from relevant advisory services to develop a robust safe handling harvesting protocol which will minimise the chances of any contamination.

Glossary

Acid

An acidic solution has a pH below 7.

Aeroponics

A system in which the roots of a plant are consistently or intermittently misted with fine droplets of nutrient solution.

Alkaline

Any solutions with a pH over 7 is considered alkaline.

BASIS

Established by the pesticide industry in 1978 to develop standards for the safe storage and transport of agricultural and horticultural pesticides and to provide a recognised means of assessing the competence of staff working in the sector.

Carbon Dioxide (CO_2)

A colorless, odorless, tasteless gas in the air necessary for plant life. Occurs naturally in the atmosphere at 400ppm.

Chlorosis

The condition of a sick plant with yellowing leaves due to inadequate formation of chlorophyll. Chlorosis is caused by a nutrient deficiency, usually iron or nitrogen; nutrient deficiencies are themselves often caused by a pH that is out of the acceptable range.

Conditioning

To soak new Rockwool in an acidic solution (pH 5.5 – 6.0) to lower the pH of the rockwool.

Dew point

The temperature of a surface at which water condenses as dew on the surface

Drip System (Drip Emitter System)

A very efficient watering system that employs a main hose with small water emitters.

Ebb-and-flow (or Flood and Drain)

A hydroponic system in which the medium is periodically flooded with nutrient solution and then drained again, feeding and aerating the medium and root system.

FACTS

The Fertiliser Advisers Certification & Training Scheme (FACTS) is a nationally validated course developed by the fertiliser industry as a form of self-regulation. It was set up in response to an E.U. investigation into the standards of competence of those advising on fertiliser use

Fungicide

A product that destroys or inhibits fungus.

Fungus

Any of a major group (Fungi) of saprophytic and parasitic spore-producing organisms usually classified as plants that lack chlorophyll and include molds, rusts, mildews, smuts, mushrooms, and yeasts. Common fungal diseases that attack plants are "damping-off," Botrytis, and powdery mildew.

Germination

The process of causing the initiation and development of a plant from seed.

F1 Hybrid

The offspring from two plants of different breeds, variety or genetic make-up which demonstrates increases vigor, disease resistance or yield

Hygrometer

An instrument for measuring relative humidity in the atmosphere.

Leaf Curl

Leaf malformation due to overwatering, over fertilization, lack of magnesium, insect or fungus damage or negative tropism.

Macronutrients

The primary nutrients N-P-K or the secondary nutrients magnesium and calcium.

Medium

The substrate or soilless material which supports the plant and absorbs and releases the nutrient solution in hydroponic horticulture.

Necrosis

The dying of plant tissue, usually the result of serious nutrient deficiency or pest attack.

NFT (Nutrient Film Technique)

A hydroponic method in which nutrient is fed into grow tubes or trays in a thin film where the roots draw it up. This "nutrient film" allows the roots to have constant contact with the nutrient and the air layer above at the same time.

Nutrient Solution

The mixture of water and water-soluble nutrients which is supplied to the plants in a hydroponic system

Photoperiod

Day length; the relationship between the length of light and dark in a 24 hour period.

Photosynthesis

The process by which plants use light energy to collect carbon dioxide from the atmosphere and convert it to chemical energy in the form of sugar.

Reservoir

The container in a hydroponic system which holds nutrient solution in reserve for use.

Rockwool

Inert, soilless growing medium consisting of woven, thin strand-like fibers made from molten volcanic rock and limestone, which is heated, extruded, and formed into slabs, cubes and blocks.

Transpiration

The movement of water from plant roots to the environment via pores (stomata) in the surface of leaves

Vermiculite

Mica which has been processed and expanded by heat. Vermiculite has excellent water-retention qualities and is a good soil amendment and medium for rooting cuttings.

Appendix 1 Composition of Fertilisers

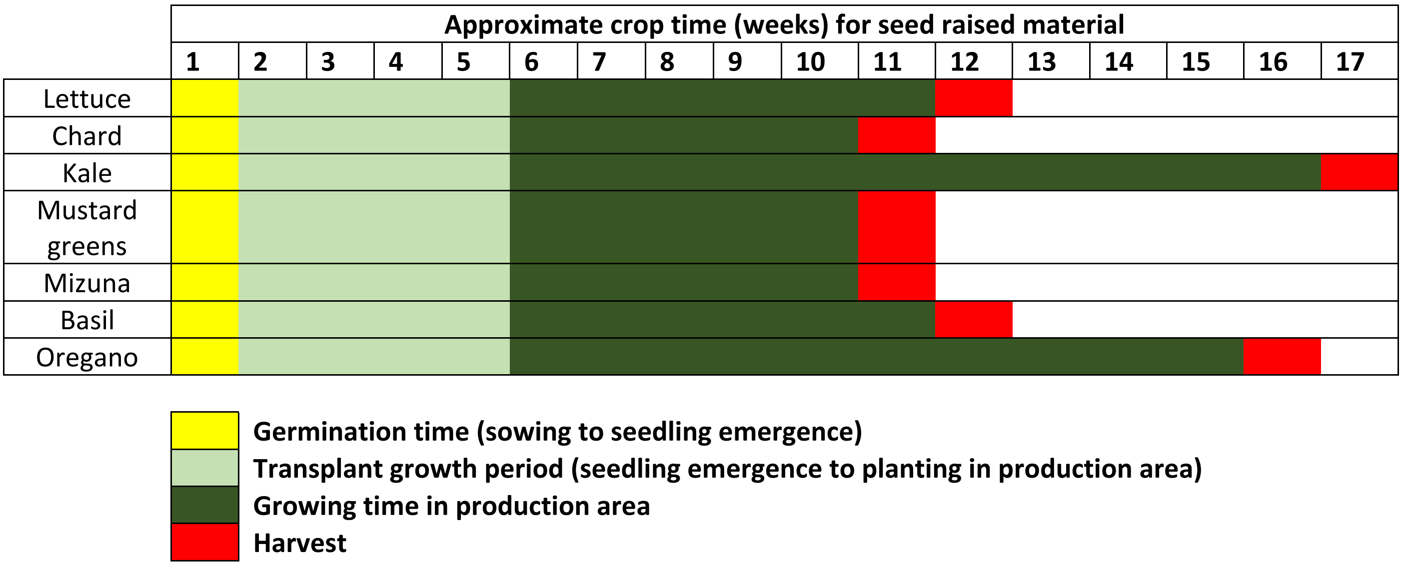
Fertiliser	Chemical composition	% of nutrient present	Molecular weight of compound	Maximum solubility (g/litre)
Nitric acid (as 100%)	HNO_3	22%N	63	Miscible
Phosphoric acid (as 100%)	H_3PO_4	32%P	98	Miscible
Sulphuric acid (as 100%)	HSO_4	47%S	97	Miscible
Calcium nitrate	$Ca(NO_3)_2.4H_2O$	15.5%N 19%Ca	236	1020
Potassium nitrate	KNO_3	13%N, 38%K	101	130
Ammonium nitrate	NH_4NO_3	35%N	80	1340
Urea	$CO(NH_2)_2$	46%N	60	670
Magnesium nitrate	$Mg(NO_3)_2.6H_2O$	11%N, 9%Mg	256	423
Monopotassium phosphate	KH_2PO_4	23%P, 28%K	136.1	330
Monoammonium phosphate	$NH_4H_2PO_4$	26%P, 12%N	115	430
Potassium sulphate	K_2SO_4	42%K, 18%S	174	80
Magnesium sulphate	$MgSO_4.7H_2O$	10%Mg, 13%S	246	850
Potassium chloride	KCl	53%K	75	280
Potassium bicarbonate	$KHCO_3$	39%K	100	523
Calcium hydroxide	$CA(OH)_2$	54%Ca	74	1.2
Iron chelate EDTA	Fe-EDTA	13% Fe	435	70
Iron chelate DTPA	Fe-DTPA	6%Fe	446	150
Iron chelate EDDHA	Fe-EDDHA	5% Fe	435	100
Manganese chelate	Mn-EDTA	13%Mn	389	100
Manganese sulphate	$MnSO_4.H_2O$	28%Mn, 13%S	169	1050
Borax	$Na_2B4O_7.10H_2O$	11%B	381	30
Solubor	$Na_2B_8O_{13}.4H_2O$	20.5%B	413	97
Copper sulphate	$CuSO_4.5H_2O$	25.5%Cu, 13%S	245	320
Copper chelate EDTA	Cu-EDTA	14%Cu	325	700
Zinc sulphate	$ZnSO_4.7H_2O$	23%Zn	288	700
Zinc chelate	Zn-EDTA	14%Zn	213	700
Sodium molybdate	$Na_2MoO_4.2H_2O$	39%Mo	242	840
Ammonium molybdate	$(NH_4)_2Mo_2O_7$	56%Mo	340	635
Calcium chloride	CaCl	35% Cl	76	600
Ammonium sulphate	$(NH_4)_2SO_4$	21%N, 20%S	132	710
Diammonium phosphate	$(NH_4)_2HPO_4$	21%N, 23%P	115	250
Potassium hydroxide	KOH	69%K	56	1120

Appendix 2 Electroconductivity, Ph and air temperature range for optimum crop growth

	Electroconductivity (mS/cm)												
	0.8	**1.0**	**1.2**	**1.4**	**1.6**	**1.8**	**2.0**	**2.2**	**2.4**	**2.6**	**2.8**	**3.0**	**3.2**
Lettuce	■	■	■	■	■	■	■						
Chard						■	■	■	■				
Kale						■	■	■	■	■	■	■	
Mustard Greens			■	■	■	■	■	■	■				
Bok Choi			■	■									
Mizuna	■	■	■	■									
Basil					■	■	■	■					
Oregano					■	■	■	■					
Mint								■	■	■	■		
Chives						■	■	■					

	pH										
	5.0	**5.2**	**5.4**	**5.6**	**5.8**	**6.0**	**6.2**	**6.4**	**6.6**	**6.8**	**7.0**
Lettuce				■	■	■	■				
Chard									■	■	■
Kale									■	■	■
Mustard Greens						■	■	■	■	■	■
Mizuna			■	■	■	■	■				
Basil							■	■	■	■	
Oregano						■	■	■	■	■	■
Mint								■	■	■	■
Chives						■	■	■	■	■	

	Air temperature (°C)													
	4	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**
Lettuce			■	■	■	■	■	■	■	■				
Chard						■	■	■	■	■	■			
Kale			■	■	■	■	■	■	■	■				
Mustard greens				■	■	■	■	■	■	■	■			
Mizuna	■	■	■	■	■	■	■	■	■	■	■			
Basil								■	■	■	■	■	■	■
Oregano					■	■	■	■	■	■	■			
Mint				■	■	■	■	■	■					
Chives						■	■	■	■	■	■			


Approximate crop time (weeks) for seed raised material
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Lettuce
Chard
Kale
Mustard greens
Mizuna
Basil
Oregano
Germination time (sowing to seedling emergence)
Transplant growth period (seedling emergence to planting in production area)
Growing time in production area
Harvest