Cereal Crops

Agricultural production has increased enormously in the last few decades, and seems set to rise even further. These increases have been brought about mainly by the development of new varieties of crops, animals and more intense methods of farming.

Maize

Originating in Central America, maize is now third only to wheat and rice in world production. It is widely grown in the USA (and Europe) as animal feed, and is also the basis of Corn Flakes and Sweetcorn for human consumption. This crop grows well where the temperature is frost-free and light intensity is high. There needs to be adequate water too – though not as much as rice needs.

One might assume that if maize crops are grown in conditions where light intensity and daytime temperatures are high then these conditions should favour photosynthesis. However this is not necessarily the case as:

- **high temperatures increase the rate of transpiration**, leading to the closure of the stomata. Closing the stomata can cause a build up of oxygen from photosynthesis in the leaves – and this reduces the rate of photosynthesis.
- if plants are grown too close together, then there will be competition for carbon dioxide.

Adaptations of maize include:

- A different biochemical pathway for photosynthesis (with an extra step) than that used by most plants. Called the **C₄ pathway**, maize plants can fix carbon dioxide at low levels as the four-carbon molecule **malate**. This molecule is then used to boost CO₂ levels in the regular C₃ pathway in a different cell. This mechanism allows photosynthesis to continue at higher rates, since the oxygen produced in the light reactions (see Module 5!) is no longer inhibiting the process. The normal limiting factor in the UK for photosynthesis is low CO₂ – at our current CO₂ levels of around 370 ppm (and rising!). Normal C₃ plants are inefficient and fail to grow at concentrations below about 200 ppm, whilst C₄ plants can successfully ‘fix’ CO₂ at levels as low as 0.1 ppm. At 370 ppm, they grow much faster.
- Remember – oxygen **competitively inhibits** the key carbon–fixing enzyme (RuBisCo) in the light-independent reactions of photosynthesis (see module 5!) i.e. beyond ‘dim’, the **brighter** the light, the **slower** photosynthesis eventually becomes.
- The roots are shallow but widespread, allowing efficient uptake of water. Maize often has small aerial roots at the base of the stem to increase their ability to withstand buffeting by wind (called buttress roots).
Sorghum is the fifth commonly grown cereal in the world and is another tropical C₄ cereal, like Maize (see above). Sorghum is adapted to **hot, arid, low-soil nutrient conditions**, reflecting its origins in the Sudan region of Africa. In the drier regions of Africa and Central India it is often a staple food, being made into a tasteless porridge, but in the rest of the world it is used as animal feed or as a source of oil and fibre. The USA is the major grower of Sorghum for this purpose. In the UK we come across it as **millet** – used as budgie food! Sorghum is able to grow well in the **very hot** (over 35°C), **very dry** regions of tropical Africa, southern USA and central India. It is able to do this by synthesising **special ‘heat-shock’ proteins** very rapidly when the temperature rises. It grows very high – up to 5 metres in a season – and the multiple seed-heads produce many thousands of small seeds from a single plant. Sorghum is a **xerophytic** plant, which means that it is well adapted to dry conditions.

**Adaptations of Sorghum include:**

- **A dense root system** that is very efficient at extracting water from the soil (both **wide** and **deep**).
- **A thick waxy cuticle** that prevents evaporative water loss through the leaf surface.
- The presence of special cells (called motor cells) on the underside of the leaf that cause the **leaf to roll inwards in dry conditions**. This traps moist air in the rolled leaf and reduces water loss.
- **Reduced number of sunken stomata** on leaves (they are in pits).
Rice

The second most widely grown cereal, rice is grown throughout the tropical and Mediterranean regions of the world. It requires a minimum temperature of 20°C in the growing season. It is the staple food of half the World’s population, and is highly nutritious. Despite its Asian origins, it is a C₃ plant. The main adaptation of rice is to an unusual habitat - uniquely, it can grow in flooded conditions (though it is not a true hydrophyte or water plant). This is the variety grown in SE Asia, where it is grown partly submerged in paddy fields for some of its life. These flooded soils ‘drown’ weeds, so reducing competition.

The land is not needed for the seedling stage of growth either, so enabling up to 3 crops per year. However, it is expensive in labour – though this is the traditional way of life for women and children in this part of the world.

Adaptations of plains rice include:

- **The stem of a rice plant has large air spaces** (hollow aerenchyma) running the length of the stem and into the roots. This allows oxygen (some formed in the plant from photosynthesis) to penetrate through to the roots which are submerged in water.

- **The roots are also very shallow**, allowing access to oxygen that diffuses into the surface layer of the waterlogged soil.

- When oxygen levels fall too low, the young plants can respire anaerobically, producing ethanol. Ethanol is normally toxic to cells, but the root cells of rice have an unusually high tolerance to it – they have a high concentration of the enzyme alcohol dehydrogenase in their cells. N.B. Adult plant roots are as intolerant of flooding as any other crop. Note that this is a physiological adaptation, whilst all the others mentioned in this section are physical or anatomical adaptations.

- When germinating, the seed grows rapidly, forcing a hollow tube or coleoptile upwards. This eventually breaks through the surface of the water, forming a ‘snorkel’ - through which the leaves eventually grow – allowing oxygen to penetrate to all parts of the plant.

## Adaptations and cropping yields of the major cereal crops

<table>
<thead>
<tr>
<th>Crop</th>
<th>Yield (kg/ha⁻¹)</th>
<th>Area grown (ha x 10⁶)</th>
<th>Growth requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>1000 - 4000</td>
<td>215</td>
<td>Warm, frost free climate, fertile soil, drought intolerant</td>
</tr>
<tr>
<td>Maize</td>
<td>1000 - 14500</td>
<td>139</td>
<td>Adapted to a wide range of temperate climates and soils</td>
</tr>
<tr>
<td>Rice</td>
<td>1500 (mountain)</td>
<td>155</td>
<td>Tropical, paddy varieties are aquatic, drought intolerant</td>
</tr>
<tr>
<td></td>
<td>4500 (plains)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Farming Methods

**Intensive Farming**
This developed after World War II. Using high-yielding hybrid cultivars and large inputs of inorganic fertilisers, together with newly-developed chemical pesticides and machine power, crop yields increased over 4 times compared to 100 years ago. Large areas planted with single crops are typical and extensive irrigation and fertiliser programmes are required. Over time, yields decline as soils are eroded or cannot recover from repeated cropping. More fertiliser leaches from the soil and enters groundwater as a pollutant. The farmer becomes more and more dependent on fossil fuels and external inputs – he becomes a ‘land-slave’.

**Extensive (or Organic) Farming**
Organic farming is a sustainable form of agriculture based on the avoidance of synthetic chemicals and applied inorganic fertilisers. It relies on mixed (crop and livestock) farming and crop management, sometimes combined with the use of natural controls (e.g. biological controls and burning), natural pesticides (nicotine and derris) and livestock and green manures. Note that ‘Organic’ is not the same as ‘pesticide-free’. Organic farming uses crop rotation to reduce pest build-up and, if well cultivated, these plots can provide food, fuel, natural pest control and fertilisers on a sustainable basis. Yields are typically lower but pest control and fertiliser costs are reduced. It is labour-intensive, but requires little external input.

**Comparison of agricultural methods**

<table>
<thead>
<tr>
<th>Intensive farming</th>
<th>Extensive (organic) farming</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td></td>
</tr>
<tr>
<td>World grain production has tripled in the last 50 years, reducing global hunger.</td>
<td>More closely matches crop to season and soil.</td>
</tr>
<tr>
<td>The cost of food has dropped as more food is now traded globally.</td>
<td>Increases crop diversity and breaks up disease and pest cycles.</td>
</tr>
<tr>
<td>Yields increase more quickly and effectively than with the alternatives.</td>
<td>Soil quality and structure improve, reducing nutrient &amp; water loss.</td>
</tr>
<tr>
<td></td>
<td>Farmers can still use new high yielding varieties.</td>
</tr>
<tr>
<td></td>
<td>Produce is pesticide-free and produced in a sustainable way.</td>
</tr>
<tr>
<td><strong>Disadvantages</strong></td>
<td></td>
</tr>
<tr>
<td>Increases in yields may not be sustainable: the rate of growth in total production is slowing</td>
<td>Yields are lower and more land is required for the same output.</td>
</tr>
<tr>
<td>Use of pesticide use is rising as their effectiveness decreases.</td>
<td>Organic produce may have more blemishes and a shorter shelf-life than sprayed produce.</td>
</tr>
<tr>
<td>Fertiliser use is increasing: soil &amp; water quality continue to decline.</td>
<td>Price may increase to offset losses.</td>
</tr>
<tr>
<td>Poor countries are reliant on outside assistance and cannot afford the cost of the fertiliser required to achieve high crop yields</td>
<td>High use of manures leads to bacterial contamination of produce.</td>
</tr>
<tr>
<td>Europe and the USA heavily subsidise agriculture, dumping the excess on world markets and Third World farmers cannot compete and so starve.</td>
<td>The choice (especially of out-of-season crops) may be restricted.</td>
</tr>
<tr>
<td>Use of ‘organic’ or old-fashioned pesticides may cause more damage to the environment than modern alternatives</td>
<td></td>
</tr>
</tbody>
</table>

Wheat Yield

![Wheat Yield Graph](image)
Manipulating the growing Environment

In a field, growing conditions can only be manipulated to a certain extent. The biotic components of the environment are under control – we can sow at the optimum density, and weed and spray against pests and diseases. But the abiotic component is much less easy to change; there is only so much that we can do. We cannot alter the climate, so the sunshine, average temperature, and days between first and last frosts are largely fixed. True, we can plough (to aerate the soil); drain or irrigate (to seek optimum water levels); plant shelter-belts (to reduce wind speed); lime (to raise the pH); and, of course, add fertilisers (to correct nutrient deficiencies).

But the three limiting factors for photosynthesis – light, temperature and carbon dioxide can only be controlled in a greenhouse or laboratory. It is important to realise that the twin Laws of ‘Limiting Factors’ and of ‘Diminishing Returns’ apply here; unless increased profits more than cover the cost, there is no point in altering anything!

Fertilisers

Since the rate of plant growth in usually limited by the availability of mineral ions in the soil, adding more fertiliser is a simple way to improve yields, and this is a keystone of intensive farming.

As well as CO₂ and water for photosynthesis, plants also need mineral ions – chiefly:
- nitrogen (NO₃) to make proteins and nucleic acids
- phosphate (PO₄) to make membranes, DNA and ASTP
- calcium (Ca) to make vitamins and the middle lamella

In addition, they need a range of other soluble ions from the soil too, but in minute quantities. Macronutrients are used in relatively large quantities i.e. Nitrate, Phosphate & Potassium (NPK) Micronutrients are needed in very small amounts, e.g. iron, magnesium, and sulphur.

If plants lack these nutrients they show specific deficiency symptoms – see table below:

<table>
<thead>
<tr>
<th>Element</th>
<th>Function in plant</th>
<th>Deficiency symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>growth, proteins &amp; nucleic acids</td>
<td>stunted growth, yellow leaves</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>nucleic acids, ATP, membranes</td>
<td>poor root growth, blue-green colour to leaves</td>
</tr>
<tr>
<td>Potassium</td>
<td>enzyme activator</td>
<td>Poor flowering; susceptible to disease; brown edges to leaves</td>
</tr>
<tr>
<td>Iron</td>
<td>manufacture of chlorophyll</td>
<td>white veins in young leaves</td>
</tr>
<tr>
<td>Magnesium</td>
<td>contained in chlorophyll</td>
<td>yellowing with green veins on old leaves</td>
</tr>
<tr>
<td>Sulphur</td>
<td>amino acids and flavours e.g. onions &amp; garlic</td>
<td>yellowing and stunting of plant in spring</td>
</tr>
</tbody>
</table>

When plants are harvested the nutrients are removed with them. In a natural ecosystem the nutrients are returned to the soil when the plants would die and decay, so growers need to use fertilisers containing these nutrients to maintain productivity. Farmers can use organic fertilisers or inorganic fertilisers.

The most commonly used fertilisers are the highly soluble inorganic fertilisers containing nitrate, phosphate and potassium ions (NPK). These are very effective but also have undesirable effects on the environment. Since nitrate and ammonium ions are very soluble, they do not remain in the soil for long and are quickly leached out, ending up in local rivers and lakes and causing eutrophication. They are also expensive and must be applied at the right time.
**Organic fertilisers** – the alternative - do less harm to the environment. Examples include animal or farmyard manure, composted vegetable matter, crop residues, and sewage sludge. These contain the same elements as inorganic fertilisers, but in organic form such as urea, cellulose, lipids and organic acids. Plants cannot these organic materials directly: their roots can only take up inorganic ions.

The organic compounds can be digested by soil organisms – chiefly bacteria - which then release the inorganic ions that the plants need (think of the nitrogen cycle).

Some advantages of organic fertilisers are:

- Since the compounds in organic fertilisers are less soluble than those in inorganic fertilisers, the inorganic minerals are released more slowly as they are decomposed. This reduces leaching and means they are longer-lasting.
- The organic wastes need to be disposed of anyway, so they are cheap.
- The organic material improves soil structure by binding soil particles together and provides food for soil organisms such as earthworms, so improving drainage & aeration.

Some disadvantages are that they are bulky and less concentrated in minerals than inorganic fertilisers, so more is needed to have the same effect. That means they are expensive to transport. They may contain unwanted substances such as weed seeds, fungal spores, heavy metals. They can also be smelly!

Increasing the amount of fertiliser increases yield, but only up to a point:

```
amount of fertiliser
```

```
This is known as the 'Law of Diminishing Returns'
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**Problems with fertilisers**

1. **Leaching**
   If the nutrients in highly-soluble inorganic fertilisers are not taken up by plants there is a danger that they will be washed out of the soil by rain water and that the run off will enter stream and rivers. This process is called leaching. The problem with this is that it may cause eutrophication, a term which is widely misused. Eutrophication means ‘an increased level of minerals in a water-course’. It does NOT mean ‘an algal bloom’, which is often the consequence of eutrophication, but is not the process itself!
2. Eutrophication

This is the process that takes place when freshwater is 'enriched' by nutrients, especially nitrates and phosphates.

The aquatic ecosystems progress from being clean water (few nutrients and algae) to **eutrophic** (murky water with many nutrients and plants). This is in fact a common example of succession. In the context of pollution “eutrophication” has come to mean a sudden and dramatic increase in nutrients due to human activity, which disturbs and eventually destroys the food chain. The main **causes are fertilisers leaching** off farm fields into the surrounding water course, and **sewage** (liquid waste from houses and factories). These both contain dissolved minerals, such as nitrates and phosphates, which enrich the water.

Subsequently, this may lead to an ‘algal bloom’, which, in turn, may lead to the deoxygenation of the water and the death of much of the animal life.

**The main source of nitrogen is farming** – either nitrates (from fertiliser over-use) or urea (from over-use of slurry/manure). Correct **timing** of fertiliser application can reduce these problems – avoiding cold soils (crops cannot absorb nutrients) and before heavy rain (nutrients leached into groundwater before plants can absorb them).

**The main source of phosphates is sewage**, which are added to detergents to improve washing performance. Sewage is also warm, so the combined effect on plant growth downstream is quite marked. Aeration of the sewage outfall increases oxygen levels and improves water quality, but does nothing to the mineral content of the water.

### Temperature

Photosynthesis is a series of chemical reactions and is dependent on temperature. As always, higher temperatures mean more collisions, more enzyme-substrate complexes and the reaction goes faster – up to the point (35 – 40°C) when the enzymes are denatured. But this applies **ONLY** if all other factors are optimal – in practice, this is not the case, since CO₂ is **always** limiting in summer and day-length and temperature are limiting in winter. So how warm should you keep your greenhouse? Well, 25-30°C is optimum (for C₃ plants – for C₄ plants it is 10°C higher), assuming you can raise the CO₂ level, otherwise growth is no faster at 35°C than at 20°C. In summer, the main problem is keeping the temperature **down**.

Remember: **Growth (or net photosynthesis) = gross photosynthesis – respiration**

If the temperature rises, so does respiration, and if photosynthesis cannot go any faster (due to lack of CO₂) then **net** photosynthesis (i.e. growth) will be **lower** at higher temperatures.

Since there is no photosynthesis at night, the ideal is warm days (~25°C) and cool nights (~15°C), together with long days (18 hours). This is exactly what northern parts of the UK experiences each summer and explains why the highest yield of wheat and barley ever in recorded was in Scotland.
Carbon Dioxide Levels

Photosynthetic organisms evolved when the concentration of carbon dioxide in the air was very different from today. For most of the last 3 billion years the Earth’s atmosphere had up to 20% CO₂ and, when the dinosaurs became extinct (65 million years ago), there was still over 5% CO₂ and oxygen levels were too low for forest fires, for instance!

In more recent times, studies confirm that CO₂ levels were lower than today - 280 ppm at the start of the Industrial Revolution (1750) – compared to 375ppm today (growing at 1.5 ppm each year).

In a sunny greenhouse in full crop, the level of CO₂ inside will be well below optimum levels so photosynthesis and growth are reduced. Growers can add extra CO₂ by one of two main methods:

1. Burning fossil fuels and releasing the flue gases into the greenhouse (thus raising temperature as well – so useful in winter/spring

2. Adding pure CO₂ from a tank of liquid (or ‘dry ice’ = solid CO₂) outside. This is very cold, so is more useful in summer.

Either method costs money and the levels of CO₂ need to be monitored carefully. The optimum level is 1000 – 1200 ppm, since photosynthesis does not increase above this point, and there is no point at all if the temperature and light are below optimum (as is likely in winter).
**The Control of Light**

Light is obviously the key ingredient in photosynthesis – as the source of energy, without it photosynthesis (= ‘light building’) could not exist. But there is more to light than day or night!

1. **Light intensity** – Whilst a sunny summer’s day can have well over 40,000 lux – and much more in the tropics – a winter’s day may have only 5-6,000 lux. This lack of light seriously restricts growth and so UK growers try to site their glasshouses on south-facing slopes overlooking the sea (or a large lake), to gain extra reflected light.

2. **Colour** – white light is a mixture of colours and plants can only use the red and blue wavelengths. Artificial lighting can be used in winter to boost natural daylight levels – but it costs a lot, and requires special Grolux tubes or sodium lamps similar to those used in B&Q and other warehouse stores.

3. **Day-length** – plants grow best in 18-hour days – a typical UK summer’s day. In winter, with 8 hours or less of daylight, plants scarcely grow at all – even when kept warm. The length of day has a dramatic effect on the flowering of most plants e.g. Christmas cacti and chrysanthemums both need a spell of short days if they are to flower.

**Control of Pests**

To farmers, a **pest** is any organism (animal, plant or microbe) that damages their crops. Some form of pest control has always been needed, whether it is **chemical** (e.g. pesticides), **biological** (e.g. predators) or **cultural** (e.g. weeding or a scarecrow). Chemical pesticides include:

- herbicides  
- insecticides  
- fungicides

Pesticides should have no adverse effect on the crop, but be effective against the pest. Normally, they kill the pests, but may slow their growth or prevent reproduction. Intensive farming is totally dependent on pesticides, and some crops are treated with 18 different chemicals to keep them pest-free.

In addition, by controlling pests that carry human disease - e.g. mosquitoes - pesticides have saved millions of human lives. However, with their widespread use and success there are problems, the mains ones being **persistence** and **bioaccumulation**.
Competition Between Crop Plants and Pests

Weed species compete with the crops for light, space, water and nutrients. Some crops are more sensitive to competition than others, but all are most vulnerable at the seedling stage.

Farmers today use ‘direct drilling’, spraying the weedkiller ‘Roundup’, at sowing time, so ensuring the crop emerges in weed-free conditions.

Ploughing is no longer used, since it:

- exposes new weed seeds to the air, encouraging them to germinate
- allows air into the soil, increasing oxidation of desirable organic matter, thus reducing it
- disrupts worm channels, reducing water penetration and drainage

‘GM’ crops have been modified to allow this weed-killer to be used on the growing crop too (it has no effect on seeds), thus further improving crop yield and Monsanto’s profits!

Animal pests (mainly insects) damage crops by feeding on them. They lower crop yield by:

1. Eating their leaves and so reducing photosynthetic area (e.g. caterpillars)
2. Sucking their sap (e.g. aphids or greenfly). This removes the products of photosynthesis.
3. They act as vectors for virus diseases.

Use of Chemical Pesticides

Insecticides act either by direct contact or are absorbed by the plant (systemic) and are then eaten by the insect. The latter has the advantages that only harmful insects are killed and rain does not wash the chemical away, so less spraying is needed.

Problems with insecticides

Some pesticides are persistent so do not break down in the environment or within the tissues of living organisms. This gives rise to two potential problems:

a) Bioaccumulation - the accumulation of a substance in living tissue. Organisms at any trophic level may be capable of bioaccumulation.

b) Biomagnification is the increasing concentration of a substance up a food chain - i.e. from one trophic level to the next. Animals at the higher trophic levels are most affected (e.g. us!).

Example

DDT was the first synthetic insecticide (1874). By killing mosquitoes, it (briefly) eliminated malaria from many tropical regions – but over-use and resistance mean that this disease is once again on the increase. Unfortunately, DDT persists in fatty tissues (bioaccumulation), whilst larger, longer-lived predators at the top of a food chain may accumulate a lethal quantity of DDT as a result of eating large numbers of smaller species (biomagnification) – see below:

Water → zooplankton → small fish → large fish → birds

<table>
<thead>
<tr>
<th></th>
<th>0.04ppm</th>
<th>0.5ppm</th>
<th>2ppm</th>
<th>25ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPARROW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPARROWHAWK</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROBIN</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CATERPILLARS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>APHIDS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEAVES</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BERRIES</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Fungicides

Fungi are the main plant pathogens and, unchecked, can cost farmers much of their crop – e.g. Potato Blight. This caused the Irish potato famine of 1848-51, and the population of Ireland to drop by 50% - either through starvation or emigration. By 1852, the use of a copper-based fungicide - Bordeaux Mixture - had contained the problem and potatoes could again be grown with success.

Blight-infected tubers turn to a brown, stinking, inedible mess

Traditional fungicides – e.g. Bordeaux Mixture – are based on heavy metals (e.g. copper). They are purely preventative, so must be sprayed on the crop before infection. Though resistance cannot build up, they are easily washed off and new growth is unprotected. They can be washed off our food before consumption and have little or no adverse environmental effects and are used by organic growers.

Systemic fungicides – e.g. Benlate. These are absorbed and carried around the plant, protecting new growth as it emerges. In addition to being preventative, they are also curative and so spraying can be reduced – a practice that led to the build-up of resistance. They have the drawback that they remain in our food when we eat it. Commercial growers use these chemicals extensively.

Integrated Pest Management

The most cost-effective form of pest control is achieved by using several different approaches together: a combination of the following is known as Integrated Pest Management.

Crop rotation. If the same crop is grown on the same piece of ground year after year pests persist from one year to the next, with the result that infestations increase in severity year on year. Crop rotation has been widely practised from the earliest times and means a different crop is grown each year in a 3 or 4 year cycle. This limits the population density of pests and diseases, especially those with annual life cycles associated with specific crops – such as potato blight.

Pest-resistant varieties. Some varieties of crop plants are naturally resistant to certain pests and diseases, and selective breeding has been used to transfer this natural protection into high-yielding strains. More recently, genetic engineering (using recombinant DNA) has served a similar purpose. The transfer of a gene across the species barrier from the bacterium *B. thuringienis* into cotton is an interesting example of conferred insect resistance – and most cotton is now ‘GM’. In the future, more pest-resistant varieties should result from the applications of biotechnology.

Biological Control – see notes (below)

Pesticide application. Integrated pest management aims to hold pests and diseases below the Economic Injury Threshold, with pesticide application held in reserve until this is reached. However, if advanced warning of an impending increase in a particular pest or disease is known, effective control can usually be achieved by applying a pesticide at the optimum time. The use of pheromone traps to measure the level of pests is now widely used, allowing fewer, more effective, spraying of crops rather than ‘preventative spraying’ which was both costly and an invitation to the pest to become resistant.
Biological control of pests

1. What are the characteristics of pest species?

They cause economic damage (e.g. eating growing crops, stored crops or damaging buildings) or have health implications (e.g. vectors of disease). Many are capable of very rapid population growth. Often the normal factors which would regulate their numbers (i.e. natural enemies) are not present, because they are alien species so their natural enemies do not exist, or because these enemies have been suppressed by insecticides.

2. What is the aim of biological control?

The aim is to depress the pest population below the Economic Injury Level (EIL): That is where the costs of the control measures start to exceed those of the extra revenue.

3. What is a suitable biological control agent?

Introduced control organisms should preferably keep the pest at low numbers because they:

- reproduce rapidly
- be specific to the pest
- have good searching capacity

4. What groups of organisms can be used for biological control?

1. Insect parasites These are generally specific in the host on which they lay their eggs. The larvae eat the host from the inside once the eggs hatch.

2. Predators. These are carnivorous and so may, in turn become a pest if, having reduced the original pest to a low level, then attack other species e.g. Cane Toad in Queensland, Aus.

3. Pathogens The best known example is the bacterium Bacillus thuringiensis, the toxin from which kills a wide range of caterpillars. If a virus is used, they are generally specific in action.

Advantages and disadvantages of biological control.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. It should not intensify or create new pest problems – the organisms used are selective.</td>
<td>1. Control is slower.</td>
</tr>
<tr>
<td>2. No manufacturing of new chemicals: the organisms are already available and so ‘organic’.</td>
<td>2. It will not exterminate the pest.</td>
</tr>
<tr>
<td>3. Control organisms will increase in number and spread.</td>
<td>3. It is often unpredictable.</td>
</tr>
<tr>
<td>4. The pest is usually unable to develop resistance.</td>
<td>4. It may well require training in its use.</td>
</tr>
<tr>
<td>5. Control is largely self-perpetuating</td>
<td>5. It is difficult and expensive to develop and supply – and where’s the developers’ profit?</td>
</tr>
</tbody>
</table>