HIGHFIELDS PUBLISHING
SAMPLE SCIENCE

Learn something of the science behind the mystery and the beauty

APPLIED PLANT SCIENCE

Cultivated plants and the manipulation of the environment to increase productivity

Contents

Adaptations of cereals

- Structural and physiological adaptations to different parts of the world
  - Rice as a swamp plant with hollow aerenchyma and a tolerance to ethanol produced by anaerobic respiration.
  - Sorghum as a plant which grows in hot, dry conditions; its xerophytic modifications include the presence of an extensive root system, a thick cuticle and a reduced number of sunken stomata; both the adult plants and the embryos can tolerate high temperatures.
  - Maize as a tropical plant with a specialised method of photosynthesis; the advantages of this method of photosynthesis in increased efficiency at high temperature and low carbon dioxide concentrations.

Controlling the abiotic environment

- Human control of the abiotic environment of crop plants
- The effect of light intensity, temperature and carbon dioxide concentration on rate of photosynthesis and productivity. Enhancement of these factors in commercial glasshouses.

Fertilisers

- The use of fertilisers to replace nutrients lost by harvesting crops.
- The advantages and disadvantages of organic and inorganic fertilisers. The relationship between yield and quantity of fertiliser added. The environmental issues arising from the use of fertilisers. Leaching and eutrophication.

Pesticides

- Interspecific competition between weeds and crop plants. Reduction of crop yield by insects either directly or indirectly by reducing the photosynthetic tissues of the plant.
- The principles of using chemical pesticides, biological agents and integrated systems in controlling pests of agricultural crops.
- The environmental issues associated with pest control. Toxicity and bioaccumulation.
- Evaluation of the issues involved in using different methods to control pests

ADAPTATIONS OF CEREALS

Cereals are seed crops derived from the family of plants known as the Graminae, or grasses. They have formed the main energy providing component (staple food) of most human diets since our early ancestors turned from a hunter-gatherer existence to the collection and cultivation of selected wild grass seeds. The civilisations of the ancient world were founded on settled agricultural communities and their cereal crops; rice in the Far East, wheat and barley in the Middle East, *Sorghum* in Africa, and maize in Central and South America. All of these crops could be eaten as whole grains, ground into flour and baked into bread of some kind, or simply mixed into a porridge-like paste.

Rice

The ancestral grass plants from which rice has been developed were adapted to live partially submerged in marshy regions. It is possible to grow rice on dry land like wheat, even in semi -temperate areas but the yield increases up to three times when it is grown in paddy fields in tropical or sub-tropical temperatures. Over half the world production is in irrigated soil, notably in the great deltas of Asian rivers such as the Ganges, Irrawaddy and Mekong. Modern varieties are fast growing, taking as little as 120 days from seed to harvest, and it is common for three crops to be produced each year. For most of the growing period the rice plants are partially submerged but the land is drained just before harvest so that the dry seed can be collected efficiently.

Most plants can not survive flooding. This is because plant roots require a good supply of oxygen for aerobic respiration. Remember that the uptake of minerals is an active process requiring high energy levels. In the absence of oxygen the roots will respire anaerobically but this can not be tolerated for long because they are soon poisoned by the ethanol released as a bi-product. Rice roots have an unusually high tolerance to ethanol and their seeds can germinate in oxygen starved soils. In common with other water adapted plants they also develop an interconnecting system of large air spaces linking the roots with the leaves and other parts above water. This specialised tissue is called **aerenchyma** and it allows the flooded roots to breathe.

Rice seeds are stripped of their outer coat and embryo (the parts containing proteins and minerals) by a process called ‘polishing’ to produce the product which you find in the supermarkets. It is virtually pure starch and provides virtually all of the daily energy intake for over 50% of the world’s population.

Maize

The ancestry of maize is uncertain. There are no modern grasses which are obviously related to it, but it is certain that the plant originated in Central America, probably in Mexico. It thrives in hot climates with well watered soils, and is adapted to photosynthesise successfully at light intensities and temperatures higher than most plants can tolerate, and with a reduced supply of carbon dioxide.

When all other conditions for photosynthesis are at their optimum level, the rate of carbohydrate production will increase with increasing light intensity until it reaches a maximum value called the **light saturation point**. At high levels of illumination the enzyme Rubisco, which normally catalyses the fixation of carbon dioxide into sugars, starts to react with oxygen in a process called **photorespiration**. Photorespiration uses up oxygen and releases carbon dioxide. It yields no useful energy and is therefore an essentially wasteful process consuming up to 25% of the carbohydrate manufactured by photosynthesis. In order to recapture the lost carbon dioxide, plants are required to open their stomata at the hottest and brightest times of day, thereby suffering a further loss of water by transpiration. This is particularly significant in tropical climates where light intensities commonly exceed the light saturation point. Maize and some other tropical plants, notably sugar cane and *Sorghum*, have evolved a mechanism referred to as **C4 photosynthesis** which overcomes the problem of photorespiration by increasing the concentration of stored carbon dioxide in their leaves. This gives them a higher light saturation point, and therefore a higher productivity.

Maize is most commonly encountered in the form of sweet corn, pop corn or tortilla chips in Western Europe. In Central and South America, maize flour is the basic material for the manufacture of tortillas, tamales and a variety of drinks. It is the single most important crop in the United States although 90% of the production is for animal feed.

Maize crop

Male flower

Female flower

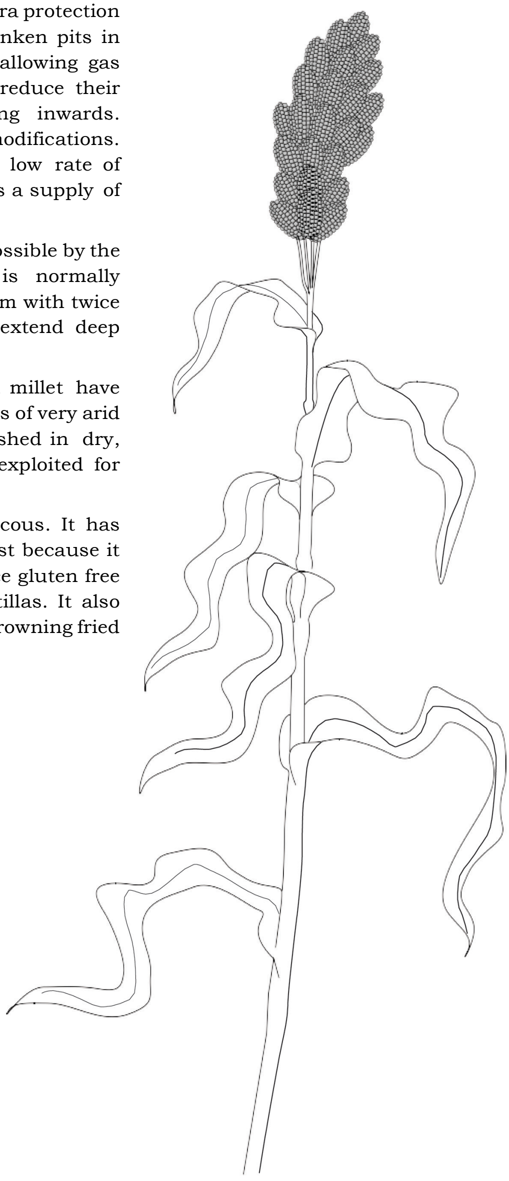
Sorghum

Like maize, sorghum is a C4 plant, specialised to maximise photosynthetic yield in high light intensities and hot climates. Compared to maize, however, *Sorghum* is able to tolerate dry conditions, requiring 20% less water to produce equivalent yields of dry matter, and is able to grow in more hostile climates than any other cereal crop. Plants which are specially adapted to tolerate dry conditions are called **xerophytes**. The adaptations (xerophytic features) centre on ways of reducing water loss whilst retaining photosynthetic activity. Sorghum is similar to maize in its general structure but its leaves are more specialised for water conservation. They are coated with a white waxy layer, giving them extra protection from desiccation, and the stomata are situated in sunken pits in order to reduce unnecessary water loss, whilst still allowing gas exchange. In conditions of water stress, the leaves reduce their exposed surface area by becoming erect and curling inwards. Photosynthetic production is not hampered by these modifications. Sorghum retains high photosynthetic yields with a low rate of transpiration. As in maize, the C4 mechanism provides a supply of carbon dioxide even when the stomata are closed.

Survival of grasses over extended dry periods is made possible by the possession of a much larger rooting system than is normally necessary. Sorghum has a very extensive rooting system with twice as many side branches as that of maize. Its roots also extend deep enough to extract water in drought conditions.

Sorghum and the even more drought resistant cereal millet have become the staple foods of people living on desert fringes of very arid land. These crops have also been successfully established in dry, nutrient depleted and wind eroded soils previously exploited for cotton production.

Sorghum is used to make bread, porridge and couscous. It has enjoyed a period of renewed market interest in the west because it yields a gluten-free flour which may be used to produce gluten free pizza bases, breakfast cereals and Mexican style tortillas. It also caramelises very easily and is suitable as a coating for browning fried foods.



CONTROLING THE ABIOTIC ENVIRONMENT

Human control of the abiotic environmental factorsaffecting productivity

A permanent increase in plant dry mass only occurs when the amount of carbohydrate produced by photosynthesis exceeds the amount oxidised in respiration and photorespiration. Remember that respiration is continuous over the whole 24 hours, whilst photosynthesis and photorespiration can only occur in the light, and it is the difference between these processes which determines plant productivity. The zero position at which the rate of photosynthesis and respiration are the same is referred to as the **compensation point**.

Productivity is measured as the gain in plant dry mass per square metre of land surface, but it is important to take into account the ratio between the leaf area of a crop and the land space it occupies. This ratio is called the **Leaf Area Index** or **LAI,** and it is calculated as the total leaf area per square metre of land. In the early stages of crop growth when new leaves are developing the LAI is small, but as more leaves are formed, it rapidly increases. Some leaves will shade each other, and in mature plants, older leaves die back as new ones are produced. For this reason it is rarely possible for a crop to use more than 95% of the available light.

Light intensity

The efficiency of light energy conversion into carbohydrate in crops depends not only on the amount of light received, but must also take into account losses through respiration and photorespiration (see above). The upper leaves of a plant tend to be illuminated at a level above the light saturation point for most plants. For a typical temperate crop, crop yields expressed as dry matter production relative to total incident light energy represent a less than 1% conversion of the solar energy input into chemical energy.

Productivity can be increased significantly by using crops bred to achieve high short term growth rates by maximising their percentage light utilisation. Crop research has also focussed on reducing losses by photorespiration, or increasing the availability of carbon dioxide which, under natural conditions, is normally the limiting factor.

Temperature

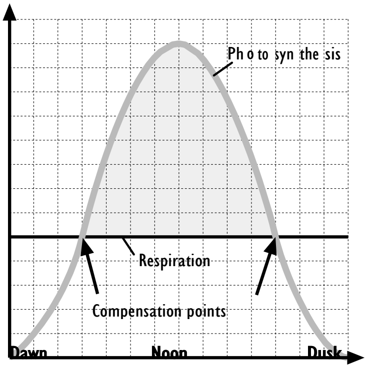
The ecological distribution of plants, their seasonal vegetative and reproductive cycles, and day to day carbohydrate assimilation, are all influenced, to a greater or lesser degree, by the ambient temperature. Temperature, like carbon dioxide and light, can be a limiting factor in photosynthesis, but it is more accurately regarded as an indirect influence, because above 15-20°C, it affects the rate of respiration more strongly than the rate of photosynthesis.

The most important factor affecting productivity is the average night temperature. 'Dark respiration' uses up twice as much assimilated carbohydrate at 25°C than at 15°C, for example, so cool nights may promote better growth.

Temperature has other indirect effects on the rate of photosynthesis, notably on stomatal opening but this is only in the extreme range. At temperatures above 30°C stomata generally close, probably as a result of higher carbon dioxide levels created by increased respiration.

Most temperate crops give their best production between 10 -15°C, but the optimum for other regions varies from 5 °C in some arctic species to 30°C for a tropical crop like maize.

Compensation points Rate

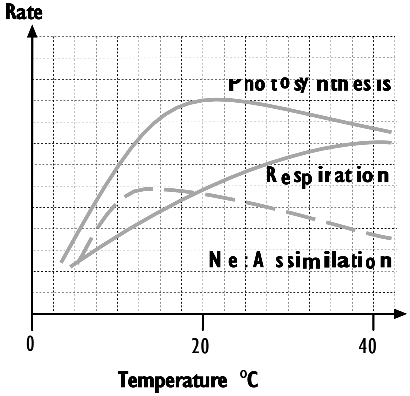


Carbon dioxide

Carbon dioxide forms a very small proportion of the atmosphere, just 0.04% by volume, but it is estimated that crop plants fix an average 160 000 kg.km^{-2}.year^{-1}. Although the quantity of carbon dioxide in the atmosphere remains relatively constant, local concentrations around a crop can range from 0.015-0.1%. Photosynthesis depletes the available carbon dioxide, particularly in a closed environment like a greenhouse. The most important source for replenishment comes from the respiration of soil organisms carrying out decomposition of dead organic matter (soil respiration). In a fertile soil with adequate dead organic matter and soil organisms, the carbon dioxide produced by soil respiration and released to the air will exceed photosynthetic requirements.

The amount of carbon dioxide available to crops is limited by the frequency and degree of opening of its leaf stomata and also by the **microclimate** which surrounds the individual leaves. Around each leaf a **boundary layer** of still air tends to reduce the concentration gradient for diffusion. Air turbulence is important to replace the layer of air which surrounds the leaf canopy. Windy conditions help to overcome the problem of carbon dioxide depletion in a field of photosynthesising maize in high light intensity.

Productivity (net assimilation)



Glasshouse production and Hydroponic Systems

An understanding of the various environmental factors controlling plant growth has led to the development of soil-free or **hydroponic** plant culture systems. Hydroponic systems provide a 'state of the art' illustration of how a detailed knowledge of the effects of abiotic factors can be applied to plant production. By maintaining all the limiting environmental and nutritional factors at their optimum level in controlled glasshouses it is possible to achieve a high yield in a small space and a short time period.

Hydroponic systems can be set up anywhere regardless of soil conditions and climate, even, as the Japanese have shown, within urban hypermarkets to provide fresh clean vegetables with zero transport and minimum packaging costs. Pest and disease problems are minimal, and weeds do not have a chance to enter the system. With no large scale mechanical cultivation and no release of agrochemicals and fertilisers into the environment, hydroponic crops are environmentally friendly, particularly in systems where the water and nutrients are recycled.

Balancing these obvious benefits are the large set-up and skilled labour costs. It must also be considered that although disease is largely eliminated, if a crop does become infected, the process can be rapid and devastating.

The most common hydroponic system for growing tomatoes, cucumbers and lettuces is the **Nutrient Film Technique,** where plants are grown within gullies made from plastic film. Typically, the gully is constructed from a sheet of plastic, 65-80cm wide, coated black on the inside and white on the outside. It is stapled together between the plants and gently inclined so that the nutrient solution drains into catchment pipes which re-circulate it via a catchment tank and associated pumping system.

If plant roots require extra aeration, the nutrient solution may be supplied intermittently (in bursts).

Problems may arise when vigorous root growth prevents circulation of fluids.

◆ CHECKPOINT SUMMARY

- Productivity is measured as the gain in plant dry mass per square metre of land surface. This reflects the relative rates of photosynthesis and respiration
- The abiotic environment includes light intensity, temperature, and carbon dioxide concentration
- Increasing light intensity increases the rate of photosynthesis up to a certain point, the light saturation point, past which there are no further gains as the result of light stimulated photorespiration
- Temperature, like carbon dioxide and light, can be a limiting factor in photosynthesis, but it is more accurately regarded as an indirect influence, because above 15-20°C, it affects the rate of respiration more strongly than the rate of photosynthesis
- The most important factor affecting productivity is the average night temperature. 'Dark respiration' uses up twice as much assimilated carbohydrate at 25°C than at 15°C, for example, so cool nights may promote better growth
- Most temperate crops give their best production between 10 -15°C, but the optimum for other regions varies from 5 °C in some arctic species to 30°C for a tropical crop like maize.

Controlling the glasshouse environment

Seasonal and climatic changes in light intensity, wavelength and duration may be compensated for in a variety of ways. Where day length influences flowering, e.g. chrysanthemums, it is controlled by the use of artificial light and/or partial shading.

The optimum temperature for tomatoes and lettuces is 18-22°C. It is important to lower the night temperature by 6-12°C in order to minimise dark respiration. Control is achieved through thermostatic monitoring and the use of heaters, vents, shades and, where necessary, coolers. The temperature directly affects humidity so fine mist sprays are linked to the same control system.

Glasshouse plants, being confined to an enclosed space, quickly use up the available carbon dioxide and so it is very important to supply this by some external means. Where heating is the norm, a hydrocarbon burner may be used to supply carbon dioxide. Alternatively, dry ice or gas cylinders may be used.

Insect pests are potentially disastrous in the glasshouse environment. They are sometimes controlled by pesticides introduced via the fine mist spray system, although biological control agents are increasingly common. In the absence of chemical insecticides, bee hives may be kept in glass houses providing natural pollinators for fruits such as tomatoes, cucumbers, and strawberries. Otherwise pollination must be achieved manually.

FERTILISERS

Crop productivity is affected by the availability of inorganic nutrients in the soil. Plants take up inorganic elements from the soil solution in the form of anions (negatively charged ions) and cations (positively charged ions). Some elements, like nitrogen, phosphorus, and potassium are required in relatively large quantities (up to 150 kg per hectare). These are called **macronutrients**. Others such as zinc and copper are needed in trace amounts only and these are termed **micronutrients**. Some make up structural components of plant cells; nitrogen, for example, is essential for amino acid synthesis, phosphorus occurs in DNA and ATP, and magnesium forms part of the chlorophyll molecule. Other elements such as potassium are involved in enzyme systems. Iron is a component of the cytochromes which make up the respiratory electron transport chain; calcium controls membrane permeability, preventing leakage of other ions from plant cells.

The mineral nutrients most frequently applied to soils as fertiliser are nitrogen, phosphorus and potassium. They are often combined in what is known as an **NPK mixture**. The relative amounts of each component and the timing of the application can influence both the development and yield of a crop. In a maize crop, for example, nitrogen is important at the end of the growing season when the protein content is being laid down in the seed.

Nitrogen is the most important limiting nutrient because without it, plants cannot make proteins. Nitrogen exists in the soil as nitrate (NO_3^-), nitrite (NO_2^-) and ammonium (NH_4^+) ions. All of these can be directly utilised by plants but by far the most commonly available form is the nitrate ion (NO_3^-). Nitrate is released as a result of the activity of nitrifying bacteria such as ***Nitrosomonas*** and ***Nitrobacter*** which oxidise ammonium compounds utilising the energy derived from these reactions to manufacture organic food compounds.

◆ CHECKPOINT SUMMARY

- ◆ The quantity of carbon dioxide in the atmosphere remains relatively constant at 0.04%, but local concentrations around a crop can range from 0.015 - 0.1%, and under natural conditions in daylight carbon dioxide is the rate regulating (rate limiting) factor for photosynthesis
- ◆ By maintaining all the limiting environmental and nutritional factors at their optimum level in controlled glasshouses it is possible to achieve a high yield in a small space and a short time period
- ◆ An understanding of the various environmental factors controlling plant growth has led to the development of soil- free or hydroponic plant culture systems.
- ◆ Where day length influences flowering as in the case of chrysanthemums it is controlled by the use of artificial light and/or partial shading
- ◆ The optimum temperature for tomatoes and lettuces is 18-22°C. It is important to vary the day and night temperature by 6- 12°C in order to minimise dark respiration. The temperature directly affects humidity so fine mist sprays are linked to the same control system
- ◆ Glasshouse plants, being confined to an enclosed space, quickly use up the available carbon dioxide. Where heating is the norm, a hydrocarbon burner may be used to supply carbon dioxide. Alternatively, dry ice or gas cylinders may be used.

Nitrate ions (being negatively charged) are not held by the negatively charged clay particles in the soil. and are very susceptible to being washed out of the soil (leaching). This causes variations in the soil concentration even on a daily basis. By contrast, ammonium ions (NH_4^+) are held by the negative charges on soil particles and are directly usable by plants.

Phosphorus is an essential component in three major biomolecules, ATP, nucleic acids and phospholipids. It is taken up by plants in the form of $H_2PO_4^-$ or HPO_4^{2-} ions. These ions do not tend to move freely in the soil and become fixed in compounds not available to plants. Up to 80% of phosphate fertiliser, normally applied in the form of 'super phosphate' (P_2O_5), can be wasted in this way, so it is sometimes introduced with the seed as it is sown, a practice called **banding**, ensuring that the nutrient is available where the roots actually grow.

Potassium is absorbed in large quantities by plant roots, reaching concentration levels up to ten thousand times that of the soil solution in some *Brassica* (cabbage and rape) species. Potassium ions have a role as activators in enzyme systems, notably in protein synthesis, and they play a key role in the opening and closing mechanisms of stomata.

Organic and inorganic fertilisers

Organic fertilisers should be seen as complementary to, rather than an alternative to, the inorganic (chemical) fertilisers described above. The main source of organic nutrients is animal waste, either in solid form mixed with bedding materials (farmyard manure, FYM) or as liquid or semi-liquid (slurry). The quality of animal manure depends on the type of animal, what it is fed on, and how much bedding is used. It is ploughed into the soil, yielding a slow release of nutrients. More importantly, it improves soil structure by binding small particles together and retaining water.

Modern intensive animal farming methods tend to use less bedding, and mechanical devices shift the dung to storage tanks in liquid or semi-liquid form. Liquid manures are potentially very hazardous to the environment. They have a high biological oxygen demand (BOD) causing eutrophication, and far from improving soil structure, they tend to create anaerobic conditions by flooding the soil air spaces. For these reasons strict regulations apply to their use where flooding may occur near rivers.

Other sources of organic nutrients include sewage sludge, seaweed, waste material from the cotton and wool industries and dried blood and bone meal. Sewage sludge whilst cheap and easily available, may contain pathogens and heavy metals and is best avoided altogether. The use of other sources depends upon the relative local costs and benefits.

Green manure

Green manure is the term used to describe the practice of growing and ploughing into the soil a green (non-seed) crop such as white mustard or clover. Green crops may be used as 'cover crops' which cover the soil during the winter months, preventing the erosion and leaching of valuable inorganic nutrients.

◆ CHECKPOINT SUMMARY

- Harvesting removes nutrients from the soil by preventing the nutrients in the crop from returning to the soil as a result of decomposition
- Crop productivity is affected by the availability of inorganic nutrients in the soil, which are supplemented by the addition of fertilisers
- The mineral nutrients most frequently applied to soils as fertiliser are nitrogen, phosphorus and potassium. They are often combined in what is known as an NPK mixture
- Nitrogen is the most important limiting nutrient
- Up to 80% of phosphate fertiliser, normally applied in the form of 'super phosphate' (P_2O_5), can be wasted by becoming fixed in compounds not available to plants
- Organic fertilisers should be seen as complementary to, rather than an alternative to, the inorganic (chemical) fertilisers described above. The main source of organic nutrients is animal waste
- Organic fertilisers improve soil by binding small particles together and retaining water
- In modern intensive animal farming methods the dung is stored in tanks in liquid or semi-liquid form. Liquid manures are potentially very hazardous to the environment. They have a high biological oxygen demand (BOD) causing eutrophication and tend to create anaerobic conditions by flooding the soil air spaces
- Green manure is the term used to describe the practice of growing and ploughing into the soil a green (non-seed) crop such as white mustard
- The main nutrient which leaches out of the soil to pollute rivers and lakes is nitrate, which acts as a fertiliser in the aquatic ecosystem causing 'super feeding' or eutrophication
- Eutrophication causes unnaturally rapid growth of plants, occasionally forming algal blooms on the surface of the water
- The increase in plant material, over a period of time leads to increased amounts of dead organic matter which become food for aerobic bacteria. Bacteria have a high biological oxygen demand (BOD) and consequently starve the other oxygen uses of essential supplies. The highest oxygen users, notably fish and certain insect larvae suffer population decline and extinction
- In extreme cases conditions become anaerobic and the ecosystem collapses.

Leaching and Eutrophication

The main nutrient which leaches out of the soil in any quantity to pollute rivers and lakes is nitrate. The effect of nitrate in aquatic ecosystems is to fertilise the water causing 'super feeding' or **eutrophication**. This causes unnaturally rapid growth of plants, occasionally forming **algal blooms** on the surface of the water. The increase in plant material, over a period of time leads to increased amounts of dead organic matter which become food for aerobic bacteria. Bacteria have a high biological oxygen demand (BOD) and consequently starve the other oxygen users of essential supplies. The highest oxygen users, notably fish and certain insect larvae suffer population decline and extinction. In extreme cases, especially in lakes and ponds, conditions become anaerobic and the aquatic ecosystem collapses. In running water there is an 'oxygen sag' immediately downstream of the source of pollution, which slowly recovers further downstream. The quantity of nitrate applied as fertiliser to the soil should be calculated on the basis of **optimum use** by the crop and not simply on maximum crop yield.

The CONTROL of BIOTIC FACTORS (PESTS and COMPETITORS)

Weeds

Weeds compete aggressively with crops for water, light and mineral nutrients and generally show better tolerance to limited supplies. They are characterised by high rates of photosynthesis, and a rapid development of roots and leaves, so they gain access to their needs more quickly than their neighbours. Weeds tend to be the first colonisers of waste and disturbed ground, more resistant than other plants to environmental extremes, and more tolerant of changing conditions. Some, like couch grass, secrete toxic or growth retardant substances called **allelochemicals** to fight off the competition.

It is very difficult to isolate the specific effects of individual weeds in a crop because several weed species compete with the crop, and with each other simultaneously for light, water, and minerals, and the resources being competed for, are often in short supply (limiting), and interrelated. One principle, however, is universal. The closer the requirements of crop and weed, the more damaging the competition, and the more difficult it will prove to control the weed. This is most obvious when the weed and crop belong to the same plant family, for example, wild oat *(Arvena fatua)* in cereal crops, fat hen (*Chenopodium album*) in sugar beet and charlock (*Sinapsis arvensis*) in oilseed rape. If the relationship is very close there is a further danger of hybridisation between weed and crop to produce an even stronger competitor.

The degree of competition between weed and crop depends largely upon the relative timing of their vegetative and reproductive cycles. Harvest yields will be affected most seriously if the growth and reproductive stages of the weed coincide with those of the crop.

Insects

The success of insects as competitors for human food may be explained by two main biological features. One is the hard exoskeletal material, **chitin**, which can be fashioned into so many different feeding accessories that no plant part is immune from attack. Consider the mandibles and maxillae of the locust and aphid. In the locust, the mandibles form pincer like cutting tools whilst the maxillae are designed to guide a leaf blade into position for biting. In the aphids, both the mandibles and maxillae are sharpened and lengthened into a piercing hypodermic structure which penetrates the tissues of plants gaining direct access to the sugary sap in the phloem.The other biological feature of insects which accounts for their phenomenal success is their ability to survive and multiply rapidly in the harshest of conditions.

Insecticides - the Chemical Approach to Control

A general distinction can be made between chemicals which act by penetrating the outer cuticle of insects, termed **contact insecticides**, and those which are ingested, the so-called **stomach poisons**.

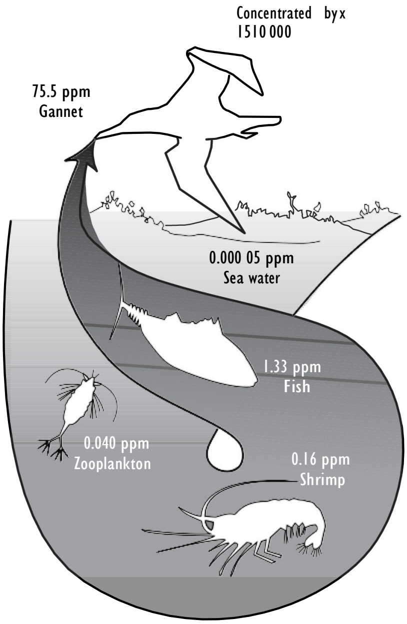
Of the older pesticides, Pyrethrum is a natural product extracted from several species of chrysanthemum (although synthetic versions have been developed) and is a contact insecticide which penetrates the cuticle of the insect as it rests against a sprayed surface.

Paris green (calcium acetoarsenite), was the first chemical insecticide used successfully on a large scale, is a stomach poison which is ingested as the insect feeds on sprayed vegetation.

Organochlorines were first developed as pesticides in the 1930s. They combine two important properties. They are **persistent**, remaining in a stable and active form for periods exceeding a year, and **residual**, accumulating in the fatty tissues without being excreted or broken down. Organochlorines destabilise the nerve membranes and tend to inhibit the respiratory enzyme cytochrome oxidase.

DDT was the first to be highlighted as having adverse effects on higher organisms quite unrelated to the target pest. The persistent and residual properties which made it so effective in eradicating the malarial mosquito and combating the insect pests of fruit trees, caused it to accumulate in natural food chains, particularly aquatic ones. Birds, such as pelicans and eagles, at the top of long food chains, diminished in number as the multiplied doses of DDT affected the shell forming mechanism in their reproductive tracts.

Organophosphates were first developed in the 1940s as poison gases for use in the Second World War. They include **parathion** and **malathion** which are still among the most widely used of all insecticides. They are easily formulated into sprays which coat the surface of leaves, and may penetrate into the epidermal tissues giving a **semi-systemic** action. When ingested by an insect pest, organophosphates act by combining with, and inactivating, the enzyme cholinesterase at nerve synapses. Cholinesterase is responsible for the removal from the synapse of the transmitter substance acetylcholine after each nerve impulse, so the result of organophosphate ingestion is the accumulation of acetylcholine in the synapses, leading to paralysis.



What are the alternatives? There are three other important approaches, namely biological control, cultural control, and the development of resistant crops, none of which alone forms a viable strategy for maintaining food levels. They should not be considered as alternatives to each other but as complementary strategies in a balanced and integrated approach to pest management.

◆ SUMMARY OF CHEMICAL CONTROL

The chemical control of insect pests poses four well publicised hazards:

- Insecticides may be directly poisonous (toxic) to man
- Insecticides may accumulate in food chains and have serious, even fatal, effects on top carnivores (including man)
- Insecticides may reduce populations of beneficial insect species.
- The use of insecticides encourages the increase of resistance in pest species.

Biological Control

Biological control involves the use of other organisms, usually predators or parasites, to reduce the numbers of a pest population. A good example is provided by the tiny parasitic wasp, *Encarsia formosa*, which has been used to control whitefly in commercial glasshouses since 1926.

Whitefly *(Trialeuroides vaporariorum)* is a sap sucking insect closely related to aphids, which owes its name to an opaque layer of wax coating its body and wings, giving it a white appearance. It is not a native British species, having been accidentally introduced from tropical America, but it thrives in glasshouses, and is very destructive of tomato, cucumber and chrysanthemum crops, not least because of its ability to transmit viral infections.

The tiny wasp, also tropical in origin, lays its eggs in young immature whiteflies referred to as 'scales' killing them before the young wasps eventually hatch out. The wasp was bred extensively for sale to glasshouse growers throughout the 30s and 40s but was made largely redundant by the advent of DDT. Biological control of whitefly using *Encarsia* enjoyed a revival in the 1970s as problems of pest resistance to chemical insecticides were recognised.

The development of a new biological control agent starts with a research programme to identify, collect and breed natural pest enemies in their natural habitat. Once sufficient numbers have been bred (and here it is important to get as much genetic variety as possible) the agent undergoes a quarantine phase in which it is assessed in laboratory conditions for its reproductive rate, climatic resistance, appetite for its pest prey, and potential threat to other organisms. After this it must undergo five years of field trials. The total cost of development is less expensive than the development of a new insecticide. Biological agents also have the advantage of reaching their target organisms in all conditions and in places inaccessible to sprays. They are keep reproducing once established in the field, and there is little chance of the pest developing resistance.

However, there are a number of problems associated with the use of biological control methods. In order to maintain a healthy breeding population of *Encarsia* it is necessary to keep the temperature of the glasshouse within very strictly controlled limits. If it is too cool, then the wasps will not breed effectively. Conversely, in warm conditions the wasps become overactive and wipe out all the young whitefly, thereby denying the next generation of its sole food supply.

You can see from this example how biological control programmes depend on carefully managed population dynamics. Despite the checks referred to earlier, there are also environmental risks resulting from a possible switch by the predator or parasite to alternative and beneficial insect prey species. New diseases are constantly imported with non-native plant introductions, many of them notifiable under strict government regulations. The penalties for delay in treatment are high, so growers are encouraged to seek rapid chemical remedies.

Cultural Control

In uncultivated land, plants, insects, and fungi co-exist within a balanced ecological system. Population numbers fluctuate, but no individual organism acquires the status of a pest. It is important to recognise that pests are created by agriculture, and the problem becomes more acute the more intensive the methods employed.

The practice of growing crops in single stands or **monocultures** accelerates the growth of particular insect populations. In uncultivated land, insects are scattered as widely as their host plants. Their populations tend to reach equilibrium at much lower densities because they encounter a greater diversity of natural enemies, and compete with each other more acutely. Intensive farming both eliminates many natural enemies, and ensures a plentiful food supply. Under such conditions, the pest population soars rapidly, reaching artificially high densities.

Cultural control is the term used to describe the application of different techniques of cultivation with the aim of reducing yield loss through pests and competitors.

Where crops are widely spaced, it is advantageous both for weed control and for moisture retention to provide ground cover between the plants. In small banana plantations this is done by **mulching** which involves covering the exposed soil surface after tillage with rotting banana leaves. A more high-tech (and costly!) version of mulching can be seen in 'pick-your-own' strawberry farms, where plastic sheeting is used to cover the ground between the rows of strawberries. A better option altogether is to fill the spaces by planting a secondary crop, for example cowpeas in maize, or groundnuts in coffee. This practice, called **intercropping** is both economically and environmentally sound.

Crop rotation is an obvious method of cultural control of insect pests. It is calculated that the maize, wheat, red clover rotation harbours up to 50 insect pest species, but no more than 3 are common to all three crops. This may be combined with the planting of mini-hedgerows, a practice referred to as **strip farming,** providing wild vegetation which will encourage the growth of natural predator populations. An ingenious method of cultural control has been used in Canada to protect wheat crops against a stem-boring sawfly. A small strip of brome grass is planted around the crop and this attracts the egg-laying female flies to deposit their cargo before reaching the wheat. When the young larvae hatch out, they tend to eat each other and little damage results to the crop. The brome grass acts as a decoy or **trap crop**.

Hygiene

Regardless of cultural practices or chemical control methods, a high degree of preventative hygiene is essential in order to avoid contamination of a crop with weed seed or fungal spores brought in on machinery or irrigation water. This is particularly important in the battle against fungal diseases. Machinery and storage facilities are disinfected after each harvest, and crop debris should be cleared, either by ploughing in or, ideally, by burning.

Integrated Crop Management

Attitudes to pest control have changed considerably over the last thirty years, not simply because of a wider consciousness and concern for environmental protection. The main change is a philosophical one, focussed by the rather late realisation that it is not possible to eliminate pest species. Instead of searching for the ultimate weapon, therefore, a more rational approach would concentrate on ways of managing pest populations.

Pest management depends upon systematic and long term evaluation of the biology of weeds, insects, and fungi, and that of their natural enemies. Computerised predictive models of infestation and crop yield assessment may be devised, and linked to weather information giving farmers early warning of potential economic damage. In this way, all the methods outlined above may be brought into play in a more coordinated manner, ensuring that war is only waged in cases where the cost of control is less than the cost of the loss in yield.

However, a new age and an additional defensive strategy has opened up with the development of transgenic resistant plants. It is now increasingly possible to manipulate all aspects of the crop, including crop protection.

Integrated crop management embraces chemical, biological, and cultural control, as well as the manipulation of plant genetics. The environmental and public health impact of any particular strategy must be assessed, both in isolation and in combination with other factors. Education of food consumers is also very important. Informed customers no longer accept indiscriminate spraying of fruit and vegetables with chemical pesticides, and they already tend to reject products from countries where such practice is common, regardless of attractive qualities such as the colour, size, price, and shelf life of the product.

◆ CHECKPOINT SUMMARY

- Weeds compete with crops for water, light and mineral nutrients and show better tolerance to limited supplies. They have high rates of photosynthesis, and development, so they out compete crop plants
- Weeds tend to be the first colonisers of cultivated ground, more resistant than other plants to environmental extremes, and more tolerant of changing conditions
- The closer the requirements of crop and weed, the greater the competition, and the more difficult to control the weed
- If related there is a further danger of hybridisation between weed and crop to produce an even stronger competitor
- Harvest yields are affected most if the growth and reproductive stages of the weed coincide with those of the crop
- The success of insects as competitors for human food may be explained by the wide variety of feeding methods, and their ability to survive and multiply rapidly in the harshest of conditions
- Contact insecticides penetrate the exoskeleton of insects, and stomach poisons are swallowed by the insect
- Organochlorines are persistent, remaining in a stable and active form for periods exceeding a year, and residual, accumulating in the fatty tissues without being excreted or broken down
- Organochlorines destabilise the nerve membranes and tend to inhibit the respiratory enzyme cytochrome oxidase
- The chemical control of insect pests poses four well publicised hazards. Insecticides may be directly poisonous (toxic) to man. Insecticides may accumulate in food chains and have serious, even fatal, effects on top carnivores (including man). Insecticides may reduce populations of beneficial insect species. The use of insecticides encourages the increase of resistance in pest species
- Biological control involves the use of other organisms to attack the pest, cultural control involves cultivation techniques which reduce conditions favourable to the pest, and the development of resistant crops involves the breeding-in of resistance to the pest
- None of these alone forms a viable strategy for maintaining food levels
- They should not be considered as alternatives to each other but as complementary strategies in a balanced and integrated approach to pest management.