AQA Biology

3.5.3 Energy and Ecosystems
3.5.4 Nutrient Cycles

Specification Section

3.5.3 Energy and ecosystems (A-level only)

Content	Opportunities for skills development
In any ecosystem, plants synthesise organic compounds from atmospheric, or aquatic, carbon dioxide. Most of the sugars synthesised by plants are used by the plant as respiratory substrates. The rest are used to make other groups of biological molecules. These biological molecules form the biomass of the plants. Biomass can be measured in terms of mass of carbon or dry mass of tissue per given area. The chemical energy store in dry biomass can be estimated using calorimetry. Gross primary production (GPP) is the chemical energy store in plant biomass, in a given area or volume. Net primary production (NPP) is the chemical energy store in plant biomass after respiratory losses to the environment have been taken into account, ie $NPP = GPP - R$ where GPP represents gross production and R represents respiratory losses to the environment. This net primary production is available for plant growth and reproduction. It is also available to other trophic levels in the ecosystem, such as herbivores and decomposers. The net production of consumers (N), such as animals, can be calculated as: $N = I - (F + R)$ where I represents the chemical energy store in ingested food, F represents the chemical energy lost to the environment in faeces and urine and R represents the respiratory losses to the environment. Primary and secondary productivity is the rate of primary or secondary production, respectively. It is measured as biomass in a given area in a given time eg $\text{kJ ha}^{-1}\text{ year}^{-1}$. **Students should be able to** appreciate the ways in which production is affected by farming practices designed to increase the efficiency of energy transfer by: • simplifying food webs to reduce energy losses to non-human food chains • reducing respiratory losses within a human food chain.	**MS 0.1** Students could be given data from which to calculate gross primary production and to derive the appropriate units. **AT a** Students could carry out investigations to find the dry mass of plant samples or the energy released by samples of plant biomass. **MS 2.4** Students could be given data from which to calculate: • the net productivity of producers or consumers from given data • the efficiency of energy transfers within ecosystems. **MS 0.3** Students could be given data from which to calculate percentage yields.

3.5.4 Nutrient cycles (A-level only)

Content	Opportunities for skills development
Nutrients are recycled within natural ecosystems, exemplified by the nitrogen cycle and the phosphorus cycle. Microorganisms play a vital role in recycling chemical elements such as phosphorus and nitrogen. • The role of saprobionts in decomposition. • The role of mycorrhizae in facilitating the uptake of water and inorganic ions by plants. • The role of bacteria in the nitrogen cycle in sufficient detail to illustrate the processes of saprobiotic nutrition, ammonification, nitrification, nitrogen fixation and denitrification. (The names of individual species of bacteria are **not** required). The use of natural and artificial fertilisers to replace the nitrates and phosphates lost by harvesting plants and removing livestock. The environmental issues arising from the use of fertilisers including leaching and eutrophication.	**PS 1.1** Students could devise investigations into the effect of named minerals on plant growth.

Key word list for 3.5.3-4

Ammonification	Production of ammonia from organic nitrogen-containing compounds e.g. urea and proteins. Saprobiontic microorganisms feed on faeces and dead organisms materials, releasing ammonia which then forms ammonium ions in the soil.
Biomass	The total mass of living material in a specific area at a given time. Usually measured in gm^{-2}. Fresh mass is quite easy to assess, but varies depending on the water content. Measuring dry mass overcomes this problem but the organism must be killed, it is usually only a small sample and may not be representative.
Biological Control	Controlling pests by introducing predators
Calorimetry	The chemical energy store in a dry mass can be estimated using this technique. When a sample of dry material is weighed and then burnt in pure oxygen within a sealed container (bomb). The bomb is surrounded by a water bath and the heat of combustion causes a temperature rise. This can be used to work out the energy released from the mass of burnt biomass.
Consumer	An organism that obtains its energy by feeding on (consuming) other organisms. Primary consumers eat producers. Secondary consumers eat primary consumers. Tertiary consumers eat secondary consumers.
Decomposer	Any organism which breaks down organic matter. Include saprophytes and detritivores.
Denitrification	Carried out by anaerobic denitrifying bacteria which convert of soil nitrates into nitrogen gas.
Detritrivores	Organisms that help saprophytes do their job. They feed on pieces of dead and decaying material and finely break it up increasing its surface area.
Ecosystem	All the living and non-living components of a particular area.
Energy Transfer	(Energy available after the transfer / energy available before the transfer) x 100
Eutrophication	Consequence of an increase in nutrient concentrations in watercourses that leads to an algal bloom, leading to light being the limiting factor for the growth of plants and algae at lower depths, leading to saprobiontic bacteria creating an increased demand for oxygen. This leads to aerobic organisms dying and anaerobic organisms populations rising. It leads to a decrease in biodiversity.
Extracellular digestion	When saprobionts release enzymes externally which break down large biological molecules into smaller ones which are then absorbed by digestion or active transport.
Fertiliser	Using these replenishes mineral ions, especially nitrates. They are necessary to improve productivity because in agriculture crops are harvested and mineral ions are not returned to the soil by decomposition by microorganisms, like would normally happen. They increase productivity because they provide minerals such as nitrogen for plants to build proteins, ATP and DNA nucleotides.
Food chain	Describes a feeding relationship in which the producers are eaten by primary consumers, which are eaten by secondary consumers, which are then eaten by tertiary consumers. These could then be eaten by quarternary consumers. Each stage is referred to a trophic level.
Food web	How food chains link together in a habitat to form a food web.
GPP	Gross primary production which is the total quantity of the chemical energy store in plant biomass, in a given time. Plants use 20-50% of this energy in respiration.
Greenhouse Gases	Gases such as methane and CO2 which trap more heat energy, raising the Earth
Guano	The excrement of seabirds and bats.
Inorganic	Type of fertiliser which are mined from rocks and deposits and then converted into different forms and blended together to give the appropriate balance of minerals for a particular crop. Contain nitrogen, phosphorous and potassium.

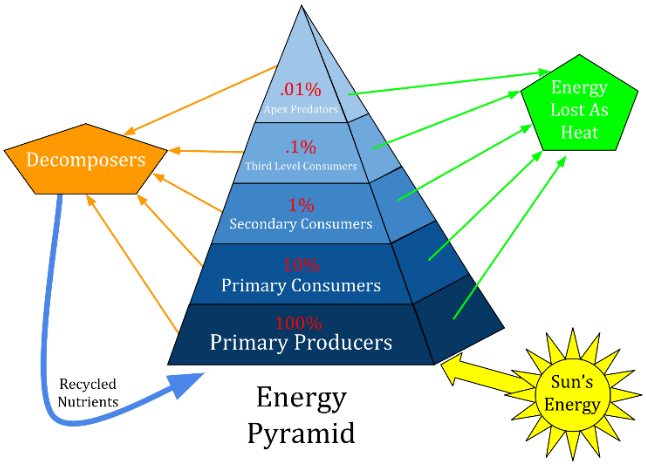
Intensive farming	A type of farming which uses processes, such as using confined spaces to restrict movement, keeping the environment warm and excluding predators, to try and make energy conversion more efficient by ensuring that as much energy from respiration as possible goes into growth rather than other activities or other organisms.
Leaching	Process by which nutrients are washed from the soil into watercourses. Rainwater will dissolve any soluble nutrients, such as nitrate ions and carry them deep into the soil, eventually beyond the reach of plant roots.
Mycorrhizae	Mutualistic association between certain types of fungi and the vast majority of plants. The fungi act like extensions of the plant’s root system and increase the surface area for absorption of water and minerals. The fungi receives organic compounds such as sugars and amino acids from the plant. The mycorrhiza act like a sponge and so holds water and minerals in the neighbourhood of the roots, enabling the plant to better resist drought and take up inorganic ions more readily. They improve the uptake of relatively scarce ions such as phosphate ions.
Nitrification	Carried out by free-living nitrifying bacteria. Some convert ammonia into nitrites and some convert nitrites into nitrates using oxidation reactions which release energy. Good drainage and ploughing prevents air spaces from being filled with water and allows nitrification to continue.
Nitrogen cycle	Four main stages: ammonification, nitrification, nitrogen fixation and denitrification. This is because all living organisms require a source of nitrogen from which to manufacture proteins, nucleic acids and other nitrogen-containing compounds.
Nitrogen fixation	Conversion of nitrogen gas into nitrogen-containing compounds. Carried out by free-living nitrogen fixing bacteria and mutualistic nitrogen-fixing bacteria which live in nodules on the roots of plants such as peas and beans. It can also be carried out industrially and occurs naturally when lightning passes through the atmosphere.
Nitrogen fixing bacteria	Carry out the process of nitrogen fixation. Can be free-living or mutualistic bacteria.
NPP	Gross primary production – respiratory losses. The chemical energy store which is left when these losses to respiration have been taken into account. This is available for plant growth and reproduction and available to other trophic levels in the ecosystem (such as consumers and decomposers).
Organic Fertiliser	Type of fertiliser which consist of the dead and decaying remains of plants and animals as well as animal wastes such as manure, slurry and bone meal.
Percentage Efficiency	Can be calculated by dividing the energy available after the transfer by energy available before the transfer x 100.
Phosphate	PO_4^{3-} ions are how phosphorous exists mostly in the form of sedimentary rock deposits.
Phosphorus cycle	Enables the cycling of phosphorous which is an important biological element as it is a component of ATP, phospholipids and nucleic acids. There is no gaseous phase in the phosphorous cycle.
Producer	Photosynthetic organism that manufacture organic substances using light energy, water, carbon dioxide and mineral ions.
Productivity	The rate of generation of biomass in an ecosystem. Usually measured in units of mass per area put unit time ($gm^{-2}y^{-1}$). Farming practices try to improve this by increasing yields by increasing the efficiency of energy transfer along the food chains which produce our food.
Pyramid of Biomass	A pyramid drawn with bar lengths proportional to the mass of plants/animals
Pyramid of Energy	A pyramid drawn with bar lengths proportional to the energy stored in organisms
Pyramid of Number	A pyramid drawn with bar lengths proportional to the numbers of organisms present
Respiratory losses	Taken away from GPP to calculate NPP.

Saprobiotic microorganism	Also known as saprophyte – an organism that obtains its food from the dead or decaying remains (detritus) of other organisms.
Selective Breeding	Breeding of organisms by human selection of parents for certain characteristics
Symbiotic	When two species live in close proximity. Mutualistic is a type of symbiotic relationship where the relationship is mutually beneficial for two organisms.
Trophic level	Each stage in a food chain
Weathering	How rocks are worn away - how phosphate ions in wastes and remains e.g. guano, bones and shells and in rocks are released into oceans, lakes and soils as dissolved phosphate ions.

Lesson 1 – Energy in Ecosystems

Notes:

Biomass



Radiation from the Sun (solar or light energy) is the main source of energy for all living things. The Sun's light energy is captured and used by producers - green plants and algae/phytoplankton (in aquatic ecosystems) during photosynthesis, to make new biomass. Most of the sugars synthesised by plants are used by the plant for respiration to release energy, the rest are used to make other groups of biological molecules such as cellulose. These biological molecules form the **biomass** of the plants. Biomass can also be thought of as the chemical energy stored in the plant. This biomass is then consumed by primary consumers (animals) which break down these biological molecules during respiration to release the chemical energy which they can use for movement, maintaining body temperature, growth and reproduction.

Measuring Biomass

Biomass can be measured in terms of mass of carbon or dry mass of tissue per given area. Dry mass is measured once all the water has been removed – this is because the amount of water in an organism can vary which will affect the overall mass.

To measure dry mass, a sample of tissue is dried in an oven set to a low temperature (so as not to burn the sample) and weighed at regular intervals until the mass becomes constant. Once the mass becomes constant all the water will have been removed. If the sample was taken in a random, unbiased way from a large population you can then scale up the biomass for the large area, e.g a field of plants. Typical units for dry mass would be kg m^{-2} (kilograms per metres squared) or kg h^{-2} (kilograms per hectare squared). If the biomass of a harvest that is grown within a specific time is being measured then it can be recorded as kg m^{-2} y^{-1} (kilograms per metre squared per year).

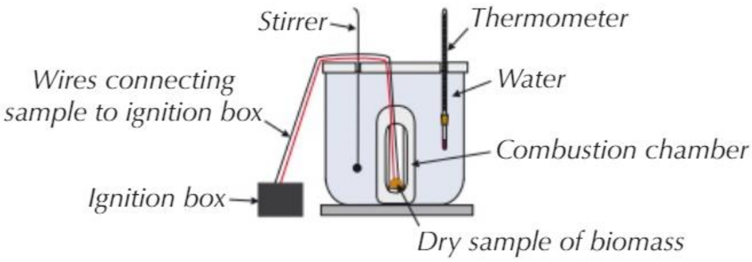


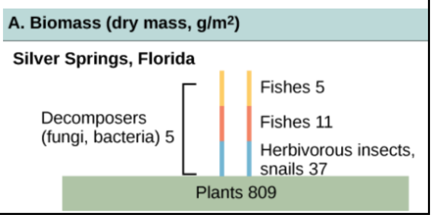
Figure 1: *An example of a calorimeter being used to measure the chemical energy in biomass.*

The mass of carbon present in the biomass of a sample can be estimated using a calorimeter. Burning the biomass and measuring the energy given off as heat (by calculating the temperature it will heat a known volume of water to) tells you how much energy in J or kJ is in the biomass.

The energy or biomass in different trophic levels of food chains can be represented using pyramids.

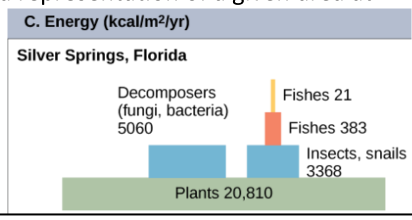
Pyramids of Biomass

These are more reliable than pyramids of individual number of organisms but they can only be estimated with a small sample which may not be representative. Drying and weighing organisms, especially animals is time consuming/ethical issues/animals contain waste that would be included in biomass.



Pyramids of Energy

They are the most accurate as two organisms of the same biomass may store different amounts of energy. 1g of fat stores 2x the amount of energy of 1g or carbohydrate. However data can be just as difficult to collect and is only a representation of a given area at one time point.



Recall Questions:

1. What is biomass?
2. What provides the energy for all ecosystems?
3. What are the organisms called which are at the start of all food chains?
4. What is most of the energy harnessed by the sun in plants used for?
5. What do animals use the energy from respiration for?
6. What are the two ways biomass can be measured?
7. Give an example of units for measuring biomass
8. How can a calorimeter be used to measure biomass?
9. What is a benefit of using pyramids of energy over biomass?
10. What is a limitation of using pyramids of biomass/energy?

Exam Questions:

Q1. Ecologists developed a method for estimating the biomass of trees in a plantation. The plantation consisted of trees of the same species.

They collected samples of wood from trees. For each sample they:

- determined the density of the freshly cut wood
- dried the wood in an oven at 103 °C for 24 hours
- determined the volume of the dried wood sample
- determined the density of the dried wood.

The table below shows data about one wood sample.

Volume of freshly cut wood sample / dm^3	**Density of freshly cut wood / g per dm^3**	**Volume of dried wood sample / dm^3**	**Density of dried wood sample / g per dm^3**
1.345	993.0	1.125	769.0

(a) The loss of mass of the wood sample was due to loss of water. Water has a density of 1 g per cm^3.

Use the data in the table to calculate the percentage of water in the freshly cut wood sample. Show your working.

Percentage of water = ____________________________________

(2)

(b) The ecologists dried the samples in an oven at 103 °C for 24 hours. Describe how the ecologists could have determined whether or not this drying removed all the water from a sample of wood.

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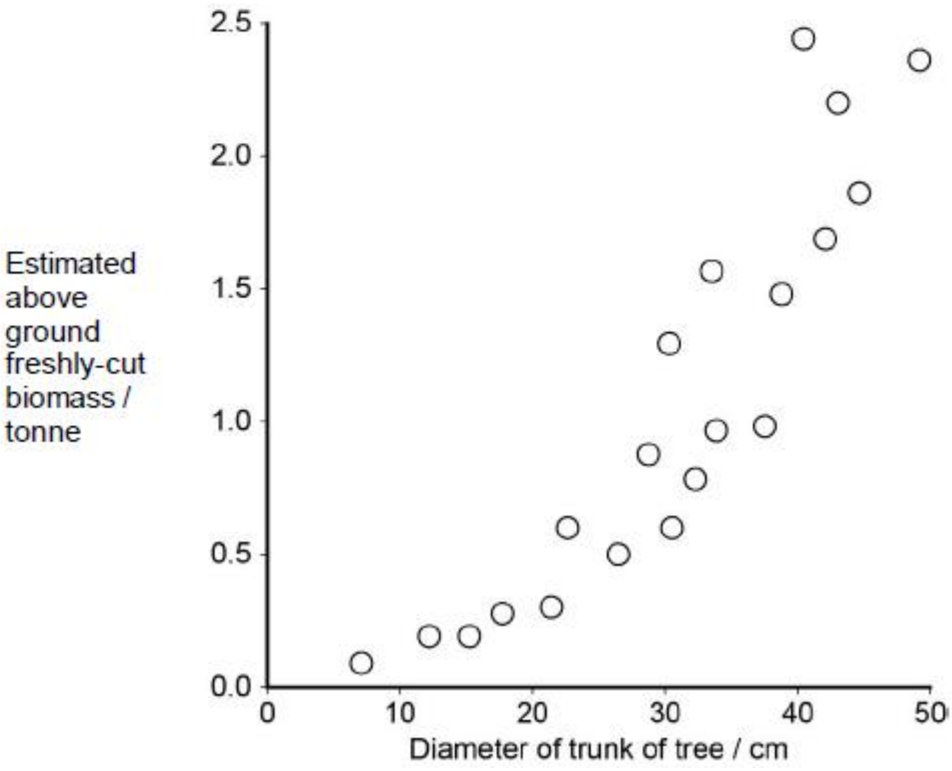
____ **(2)**

(c) Ecologists then investigated the relationship between the diameter of the trunk of the trees and their biomass.

The graph below shows their results. Each point is the result for **one** tree.



What does the graph show about the relationship between the diameter of the trunk of the trees and their biomass?

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(2)

(d) Plantations of trees are often created to remove carbon dioxide from the atmosphere, to help to balance the carbon dioxide released by burning fossil fuels.

For different species of tree, information is available for:

- the relationship between diameter of trunk and freshly cut biomass
- the percentage of water in fresh-cut wood
- the mean dried density of wood.

Using only the information provided in part **(c)**, suggest how the mass of carbon in the wood of a plantation of trees of a particular species could be estimated.

Start with measuring the diameter of a large number of trees.

Assume that the dry biomass of a tree consists of biological molecules that contain carbon.

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(4)

Q2. The Harvest Index is the percentage of dry biomass that is harvested and used.

Barley is a cereal. It is grown for its grain. Researchers collected data to calculate the Harvest Index of barley growing in a small field. They obtained their measurements from quadrats at different places in the field. Their results are shown in the following table.

Quadrat number	**Dry biomass of barley plants / g m^{-2}**	**Dry biomass of barley grain harvested / g m^{-2}**
1	80	42
2	75	37
3	82	41
4	93	39

(a) Use the data for quadrat number **4** in the table to calculate the Harvest Index for barley. Show your working.

Harvest Index = ______________________

(2)

(b) Plant breeders are trying to produce barley plants with shorter stems. Explain how this would increase the Harvest Index.

(1)

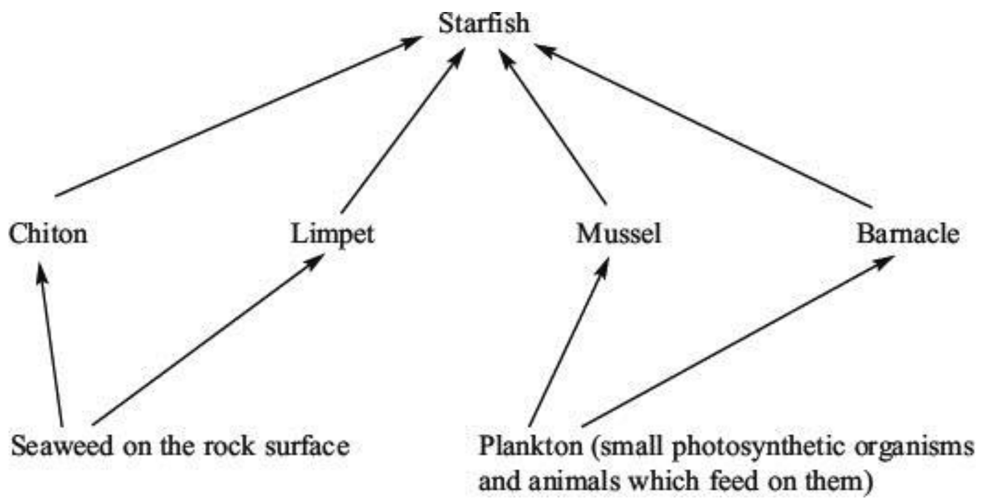
(c) The values for the biomass of the barley plants are different in each quadrat. Suggest an explanation for this difference.

(2)

(d) The researchers measured the dry biomass of the barley plants and the barley grain. What is the advantage of using dry biomass for these measurements?

(2)

Q3. Starfish feed on a variety of invertebrate animals that are attached to rocks on the seashore. The diagram shows part of a food web involving a species of starfish.



(a) When starfish feed on mussels they leave behind the empty shell. Explain how quadrats could be used to determine the percentage of mussels that had been eaten by starfish on a rocky shore.

(3)

(b) The table shows the composition of the diet of starfish.

	Prey species			
	Chitons	Limpets	Mussels	Barnacles
Percentage of total number of animals eaten	3	5	27	65
Energy provided by each species as a percentage of total energy intake	42	5	38	15

(i) The percentage of barnacles in the diet is much higher than the percentage of energy they provide. Suggest **one** explanation for this difference.

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(1)

(ii) The table shows that the amount of energy provided by chitons is greater than the amount of energy provided by limpets. Calculate the number of limpets a starfish would need to eat in order to obtain the same amount of energy as it would obtain from one chiton.

Number of limpets ______________________

(1)

Q4. Yield can be determined by measuring the dry mass of plants.

(a) Suggest how you could determine the dry mass of a sample of plant material.

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(2)

(b) What is the advantage of using dry mass and not fresh mass to compare the yield of plants?

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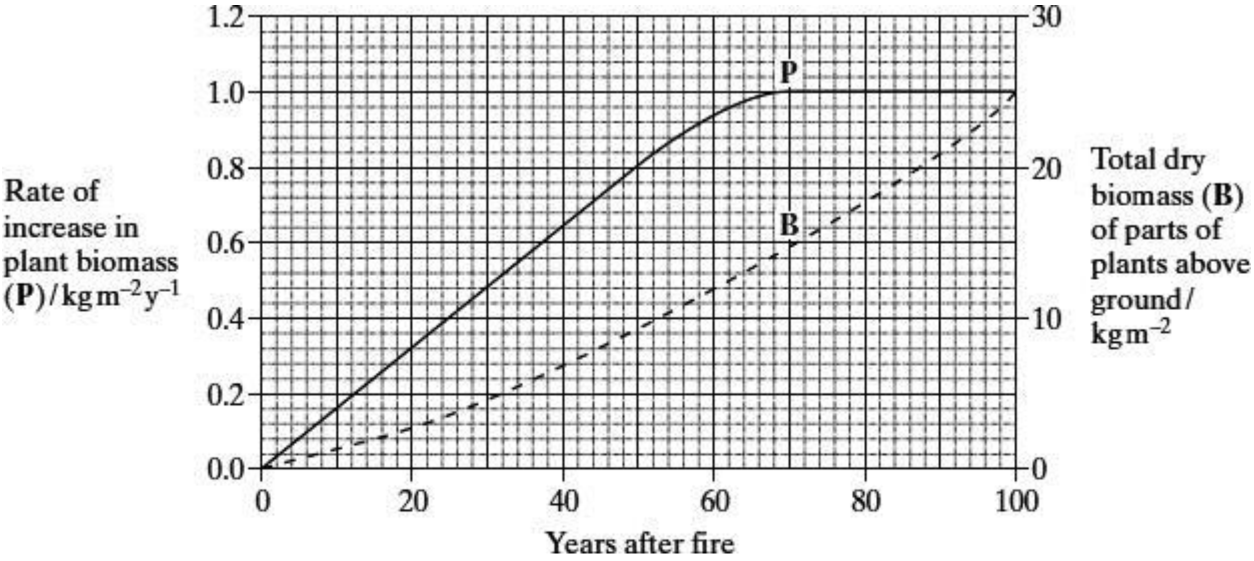
____ **(2)**

Q5. A fire destroyed a large area of forest in North America. The process of succession was studied until the forest was re-established. The rate of increase in plant biomass, **P**, was determined at regular intervals. Also, the total biomass of the parts of plants above ground, **B**, was measured in sample areas.

The graph shows the results for the first 100 years after the fire.



(a) Ten years after the fire most of the area was covered with herbaceous plants.

(i) Describe how you could measure the dry biomass of the parts of the herbaceous plants above ground in a sample area of 1 m^2.

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____ **(3)**

(ii) How could the researchers make sure that they obtained reliable data for the total biomass (**B**)?

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____ **(2)**

(iii) Suggest **two** limitations involved in measuring the rate of increase in plant biomass (**P**) which would affect the accuracy of the data.

1. ____

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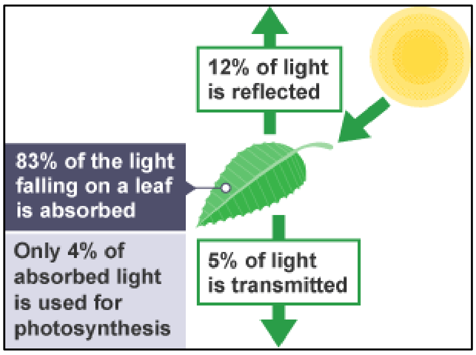
2. ____

____ **(2)**

Lesson 2 – Productivity and Agriculture

Notes:

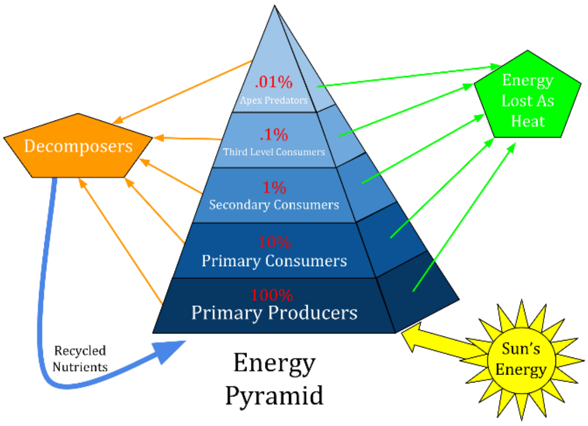
Productivity is described as the rate of generation of biomass in an ecosystem. Usually measured in units of mass per area put unit time ($gm^{-2}y^{-1}$).



Gross primary production (GPP) is the total amount of chemical energy converted from light energy by plants in a given area. Not all light energy from the sun is converted to chemical energy by plants, this is because some light energy is:

- Reflected
- Transmitted through the leaf
- Is the wrong wavelength
- Hits parts of the plant that cannot photosynthesis (e.g bark of a tree)

Approximately 50% of GPP is lost to the environment as heat when the plants respire, this is known as the respiratory loss. The remaining chemical energy is called the net (overall) primary productivity (NPP). NPP is the energy available to the plant for growth and reproduction and is stored in the plant biomass – thus it is also the energy available to organisms that consume the plant. It can be calculated like this: **NPP = GPP – R.**



Primary consumers then also store energy in their biomass that can be passed on to a secondary consumer or a decomposer – this is known as secondary productivity. Not all the chemical energy from the consumers food is transferred to the next trophic level – about 90% of the energy is lost because:

- Not all food is eaten e.g plant roots or bones/hair so the biomass is not taken in to be broken down
- Some parts are indigestible so the energy in these parts are returned to the environment in faeces
- Some energy is lost to the environment as heat produced during respiration and during excretion of urine

The net (secondary) production (N) is the energy that is left and stored in the consumers biomass which is available to the next trophic level. It can be calculated using the following formula: **N = I – (F + R)**

I = energy in ingested food, F = energy lost in faeces and urine, R = energy lost in respiration

This explains why food chains can only support 4/5 trophic levels because the net production is very low at the top of the food chain, so apex predators must eat large amounts of prey to consume enough energy. However, as you move up the food chain energy transfer becomes more efficient because plants contain more indigestible matter than animals. You can calculate the efficiency of energy transfer between trophic levels:

% efficiency of energy transfer = (net production of trophic level / net production of previous trophic level) x 100

Farming practices try to improve NPP of crops and the NP of livestock by increasing yields by increasing the efficiency of energy transfer along the food chains which produce our food. They do this in two ways:

1) Reducing the energy lost to pests by simplifying food webs – pests that eat crops reduce the amount of energy available to humans. Farmers reduce pests using chemical pesticides e.g insecticides to kill insects and herbicides to kill weeds which compete with crops for energy from the sun. Biological controls such as ladybirds to kill aphids.

2) Reducing the respiration of livestock – controlling the conditions animals are kept in so that more energy is used for growth and less for respiration or activities that increase respiration rate such as movement and keeping warm e.g by using heated, small pens. This reduces costs and more food is produced in less time.

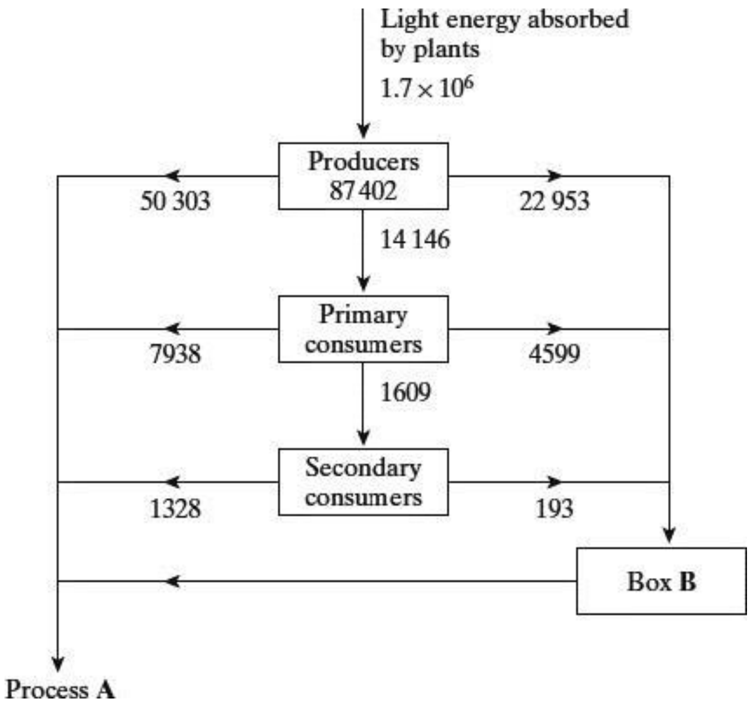
However, there are ethical issues with this as it restricts the natural behaviour and can cause pain through uncomfortable conditions. Diseases could also be more likely to spread when animals are kept close together in warm environments. Using chemical pesticides and herbicides can also have a negative impact on the surrounding environment such as reducing biodiversity and causing eutrophication.

Recall Questions:

1. What is GPP?
2. What don't plants take in all of the available energy?
3. What is NPP?
4. What is primary productivity?
5. What is secondary productivity?
6. State the equation that links NPP/GPP/R
7. How can you calculate the efficiency of food chains?
8. Why isn't the transfer of energy from producers to primary consumers very efficient?
9. What do farmers do to improve NPP and efficiency in crops?
10. What do farmers do to improve NPP and efficiency in livestock?

Exam Questions:

Q1. The diagram shows the energy flow through a freshwater ecosystem. All units are kJ $m^{-2}year^{-1}$.



(a) Name

(i) process **A**;

______________________________ **(1)**

(ii) the group of organisms represented by box **B**.

______________________________ **(1)**

(b) Calculate the percentage efficiency with which light energy is transferred to energy in producers. Show your working.

Answer ____________________ **(2)**

(c) Describe the effect of light energy in the light-dependent reaction of photosynthesis.

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____ **(2)**

(d) If a plant is kept in the dark it is still able to produce carbohydrates, as long as it is provided with two products of the light-dependent reaction of photosynthesis. Give the name of these products and explain their function in the light-independent reaction of photosynthesis.

Name ____

Function ____

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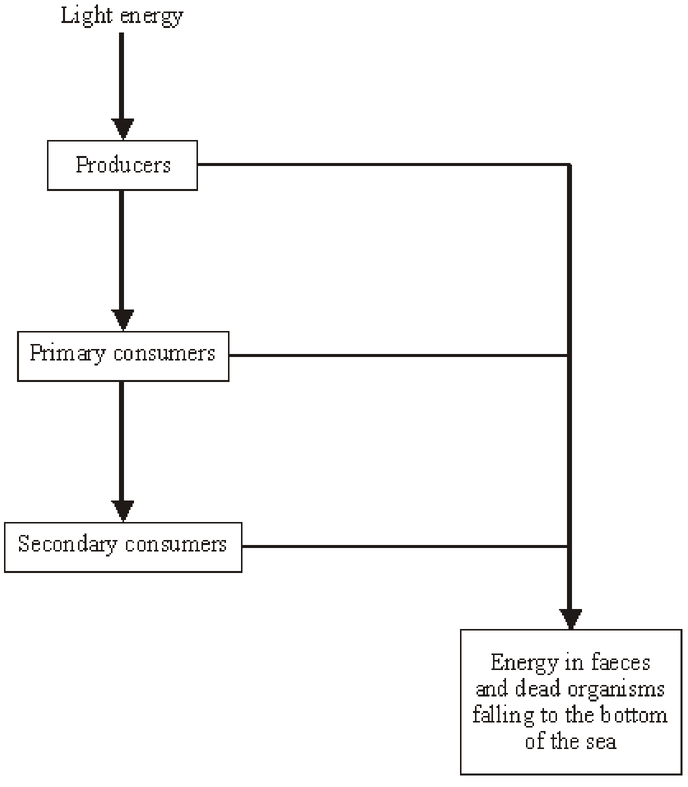
Name ____

Function ____

____ **(4)**

Q4. The diagram shows the flow of energy through a marine ecosystem.



(a) Give **one** reason why not all the light energy falling on the producers is used in photosynthesis.

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(1)

(b) The producers in this ecosystem are seaweeds, which have a large surface area to volume ratio. Give **two** advantages to seaweeds of having a large surface area to volume ratio.

1. ____

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2. ____

____ **(2)**

(c) Some species of seaweed are submerged in water for most of the time. Explain how being under water might affect the rate of photosynthesis.

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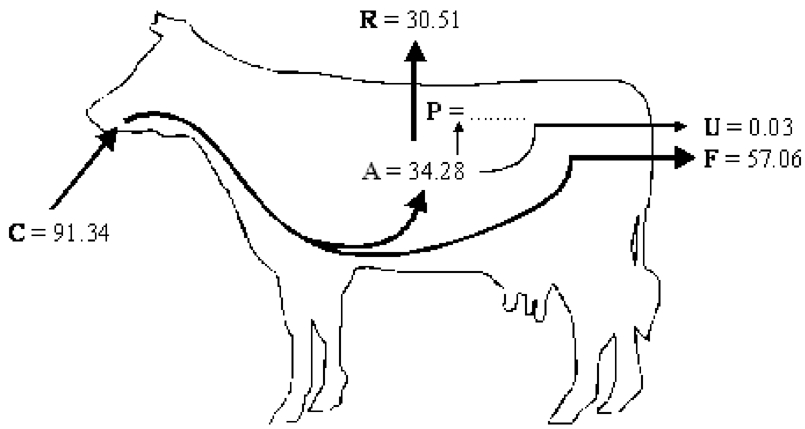
____ **(3)**

Q5. The diagram shows the transfer of energy through a cow. The figures are in kJ × 10^6 $year^{-1}$.



Key: **A** = energy absorbed from the gut
C = energy consumed in food
F = energy lost in faeces
P = energy used in production of new tissue
R = energy lost by respiration
U = energy lost in urine

(a) (i) Complete the following equation for the energy used in the production of new tissue. Use only the letters **C**, **F**, **R** and **U**.

P = ____

(1)

(ii) Calculate the value of **P**.

P = ____________________ kJ × 10^6 $year^{-1}$ **(1)**

(b) It has been estimated that an area of 8100 m^2 of grassland is needed to keep one cow. The productivity of grass is 21 135 kJ m^{-2} $year^{-1}$. What percentage of the energy in the grass is used in the production of new tissue in one cow? Show your working.

Answer ____________________ %

(2)

(c) Keeping cattle indoors, in barns, leads to a higher efficiency of energy transfer.

Explain why.

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___ **(1)**

Q6. Detritivorous insects feed on the dead remains of plants. Some students estimated the numbers of detritivorous insects at two different sites in an ecosystem. They also obtained data about the net primary production of the sites to see if this influenced the numbers of insects present. Net primary production is a measure of plant biomass formed per year. The results are shown in the table.

Site	**Number of insects per m^2**	**Net primary production / g m^{-2} y^{-1}**
A	316	1440
B	90	550

(a) Explain how the students could use the mark-release-recapture technique to estimate the numbers of insects.

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___ **(4)**

(b) The students used the chi-squared (χ^2) test to test the hypothesis that there was no significant difference between the numbers of insects per square metre at sites **A** and **B**. The value they obtained was 125.8. They checked this value in χ^2 tables.

(i) How many degrees of freedom should they check against?

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(1)

(ii) What level of probability is normally used to judge whether a difference is statistically significant?

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(1)

(iii) The value of χ^2 for the 0.001 level of probability for this number of degrees of freedom is 10.8. What does the value obtained by the students suggest about the difference in numbers of the insects per square metre between the two sites?

Explain your answer.

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(2)

(c) (i) Explain why the net primary production of an area does not represent the total amount of plant biomass formed per year by photosynthesis.

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(2)

(ii) Suggest how the difference in net primary production of sites **A** and **B** might explain the difference in the number of insects between the sites.

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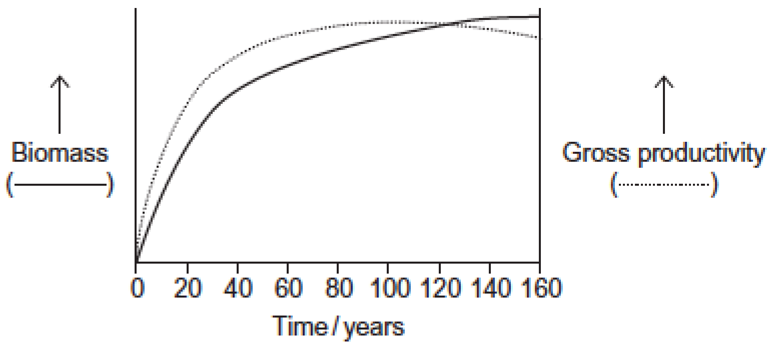
(1)

Q7. The graph shows how gross productivity and biomass in an area changed with time in the succession from bare soil to mature woodland.



(a) (i) Suggest appropriate units for gross productivity.

____ **(1)**

(ii) Explain the decrease in gross productivity as the woodland matures.

____

____

____

____

____ **(2)**

(b) Use your knowledge of succession to explain the increase in biomass during the first 20 years.

____

____

____

____

____ **(3)**

(c) Use the information in the graph and your knowledge of net productivity to explain why biomass shows little increase after 100 years.

____

____

____

____ **(2)**

(d) Suggest **one** reason for conserving woodlands.

____

____

____ **(1)**

Q8. Scientists measured the mean temperature in a field each month between March and October. The table shows their results.

Month	Mean temperature /°C
March	9
April	11
May	14
June	17
July	20
August	18
September	16
October	14

(a) The gross productivity of the plants in the field was highest in July.

Use the data in the table to explain why.

____

____

____

____

____ **(2)**

(b) (i) Give the equation that links gross productivity and net productivity.

____ **(1)**

(ii) The net productivity of the plants in the field was higher in August than in July. Use the equation in part (b)(i) and your knowledge of photosynthesis and respiration to suggest why.

____

____

____

____

____ **(2)**

(c) A horse was kept in the field from March to October. During the summer months, the horse was able to eat more than it needed to meet its minimum daily requirements.

Suggest how the horse used the extra nutrients absorbed.

____

____

____

(1)

(d) The horse's mean energy expenditure was higher in March than it was in August. Use information in the table to suggest why.

____

____

____

____

____

(2)

Homework:

Task 1: Complete the sentences using the words in bold

4 or 5 chlorophyll community digested eaten endotherms energy excretory heat heterotrophs higher kill limiting little movement producers proportional pyramid of biomass pyramid of energy pyramid of numbers reflected relationships respiratory saprobionts time transfer of energy trophic level unrepresentative wavelengths

Food chains describe a feeding relationship by showing the ___________ __ __________ between producers and consumers. Each stage is referred to as a __________ ________. Arrows represent the direction of energy flow. However, most organisms in a _____________ do not just feed upon one animal, and one animal can be fed upon by many other animals, a food web shows some of the feeding _______________ within the community.

Most of the light energy arriving from the sun is not converted by plants into chemical energy because:

- most of the light is ____________ back into the atmosphere by clouds
- not all _____________ of light are used for photosynthesis (e.g. all green light is reflected)
- light may not fall on the ____________ molecules so cannot be used in photosynthesis
- a __________ factor may slow the rate of photosynthesis e.g. low temperatures

The rate at which plants store energy is called net production and is represented by the formula:

Net production= gross production – ______________ losses

Also, only a low percentage of energy is transferred between each trophic level of the food chain because:

- Some of the organism is not __________ e.g. bones, wood
- Some parts cannot be ___________ so are lost in faeces e.g. connective tissue, cellulose
- Some energy is lost in ____________ materials e.g. urine, carbon dioxide
- Much of the energy is lost as _________, particularly in _____________ since they maintain a constant body temperature
- Energy is also lost in ____________ e.g. during hunting

Most food chains don't have more than ___ ___ ___ trophic levels since there is insufficient energy transferred to support more. As a result of this energy loss, the combined mass of organisms (biomass) is less at _________ trophic levels and so the total amount of energy stored at each level is also less. Energy transfer between each trophic level is typically only around 15%, and can be calculated by:

$$\text{energy transfer} = \frac{\text{energy available after the transfer}}{\text{energy abailable before the transfer}} \quad \text{x100}$$

Pyramids are sometimes constructed to show information about the organisms and energy in food chains; the width of the block is ______________ to the units under study at each level. All pyramids are difficult to construct since it is hard to find, count or catch all individuals.

____________ ___ ___________ show the number of organisms at each trophic level. These pyramids provide __________ useful information since organisms in the food chain have different masses and different energy content.

____________ ___ ___________ show the biomass of all living organisms at each trophic level. Wet mass can be used but gives _______________ results since different organisms have different water content. Dry mass is often used (by drying organisms at 80°C for 48h) but it is not always desirable to ______ organisms.

____________ ___ ___________ show the flow of energy at each trophic level during a fixed period of _______. These contain much useful information on the functioning of an ecosystem but are difficult to construct since the total energy content of each trophic level must be calculated using calorimetry.

Task 2: Answer the questions

1. Why might food chains often terminate before the 5th trophic level? [4]

....

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....

2. Name all of the secondary consumers in the food web [1]

....

....

....

....

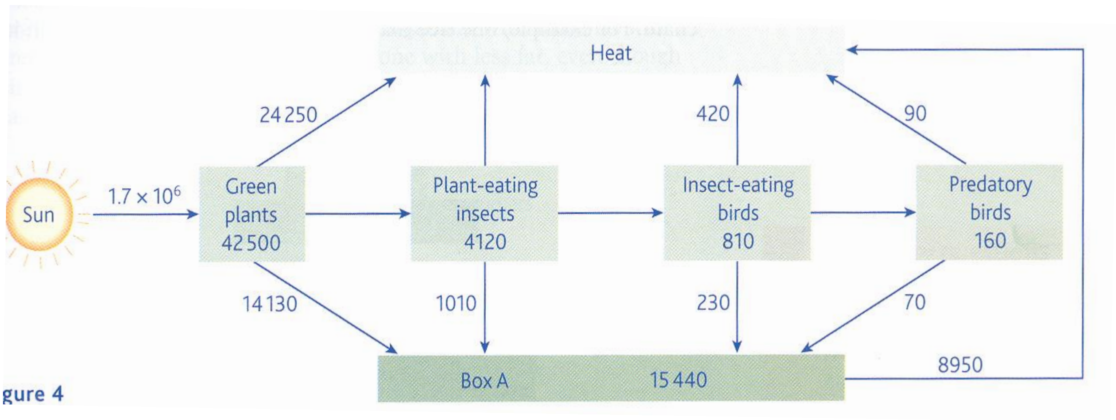
3. Why will a community will be more stable if it has a large number of interconnections within its food webs? [2]

....

....

....

4. How much energy is lost as heat by the plant-eating insects in the food chain below? [2]



....

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5. Explain why, when estimating the dry mass of a sample, the material is heated to just below 100°C and then cooled in a desiccator until constant weight is attained.

....

....

6. Explain why wet weight is a very inaccurate measurement and measuring dry mass causes damage to the sampled habitat when constructing pyramids of biomass. [3]

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A study of a woodland food chain produced the pyramid of energy to the right. All values are in KJ $m^{-2}Yr^{-1}$.

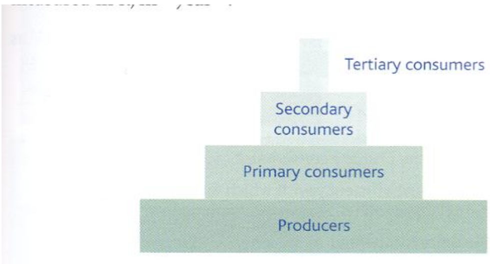


Figure 3 *Pyramid of energy based on oak trees*

sparrowhawk

2 robin

06 moth caterpillars

978 beech trees

7. Draw a labelled diagram of the pyramid of numbers and a pyramid of biomass for this food chain. [4]

8. Calculate the % efficiency with which energy is transferred from moth caterpillars to robins. [2]

....

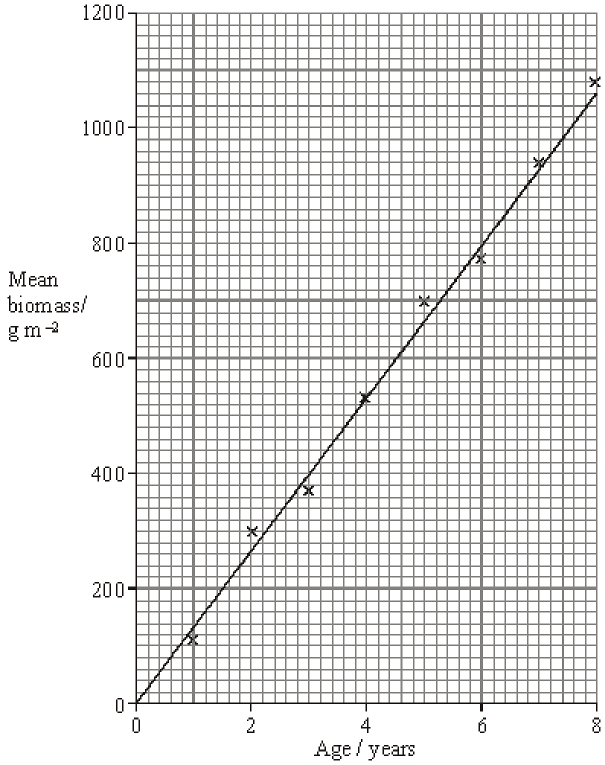
....

9. Define net productivity. [1]

....

Task 3: Answer the exam questions

Q1. The graph shows the mean biomass of heather plants of different ages growing on a moor.



(a) (i) When completely burned, 1 g of heather releases 22 kJ of energy. Use the graph to calculate the mean amount of energy stored as heather biomass per year. [1]

Answer .... kJ m–2

(ii) The total amount of light energy falling on the leaves of heather plants per year is 3 150 000 kJ m–2. The chlorophyll in the leaves of the heather absorbs only 45 % of this energy. Calculate the percentage of the total amount of energy absorbed by the chlorophyll per year which is stored as heather biomass. Show your working. [2]

Answer .... %

(iii) Only a small percentage of the light energy absorbed by the chlorophyll is stored as biomass. Suggest two explanations for this. [2]

1 ....

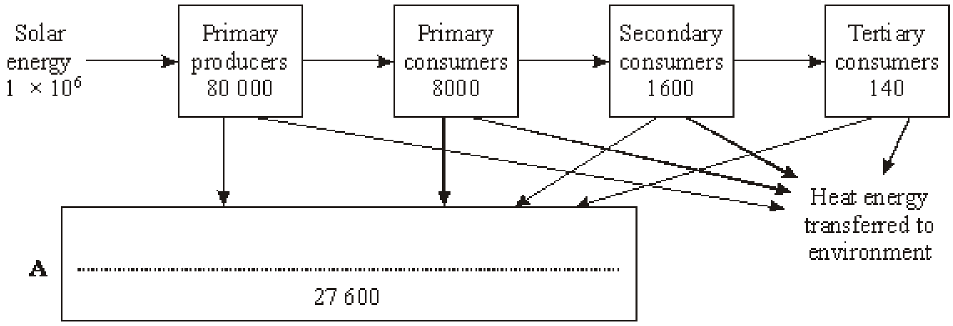
....

2 ....

....

(Total 5 marks)

Q2. The diagram shows the energy transfer through the trophic levels in an ecosystem. The numbers in the boxes show the amounts of energy in the biomass at each trophic level.



(a) Complete box A in the diagram with the name of a group of organisms. [1]

(b) Suggest suitable units for energy transferred between trophic levels. [2]

....

(c) Give three explanations for the difference between the amount of solar energy reaching the primary producers and the energy in the biomass of the primary producers. [3]

1 ....

....

2 ....

....

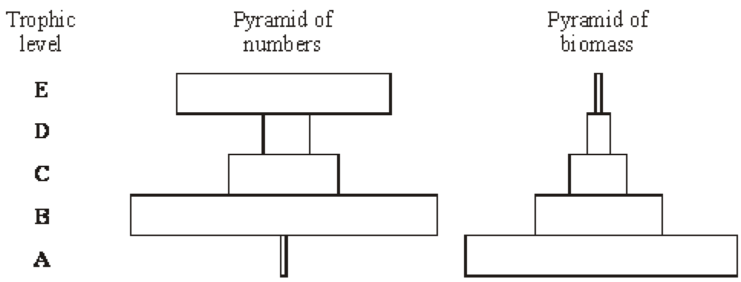
3 ....

....

Q4. A food chain found in oak woodland is shown below.

Organism	Oak Tree →	Aphid →	Hoverfly →	Great tit →	Parasitic mite
Trophic level	**A**	**B**	**C**	**D**	**E**

The pyramid of numbers and pyramid of biomass representing this food chain are shown in the diagram.



(a) Explain the difference between the shapes of the two pyramids at trophic levels D and E. [2]

....

....

In the activated sludge method of sewage treatment, organic matter in untreated sewage supplies nutrients to bacteria in the treatment tank. These bacteria include decomposers and nitrifying bacteria. The bacteria are eaten by ciliated protoctistans, which are, in turn, eaten by carnivorous protoctistans.

(b) (i) Sketch and label a pyramid of energy for the organisms found in the treatment tank. [1]

(ii) Explain what causes this pyramid of energy to be this shape. [2]

....

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....

Recall Question Answers

Question	Answer
What is GPP?	The rate at which chemical energy is incorporated into organic molecules by an ecosystem
What is NPP?	The rate at which chemical energy is incorporated into organic molecules that make up the new plant biomass
What is primary productivity?	The rate at which energy is incorporated into organic molecules
What is secondary productivity?	The amount of energy from the organism that passes on to it's consumer or decomposer
State the equation that links NPP/GPP/R	NPP= GPP-R
How do you calculate the efficiency of food chains?	Energy available after transfer/energy available before transfer) x 100
Why isn't the transfer of energy from producers to primary consumers very efficient ?	Not all of the available food is eaten (roots, bones twigs),some undigested food remains in faces (cellulose in cell walls), much of the food absorbed by the consumers is used in respiration
What is net productivity?	The energy that is used for biomass and is available to the next trophic level
What is gross productivity ?	the available energy that is taken in
What don't plants take in all of the available energy?	some light energy is reflected, transmitted through the leaf, is the wrong wavelength or hits parts of the plant that cannot photosynthesis (bark of a tree)

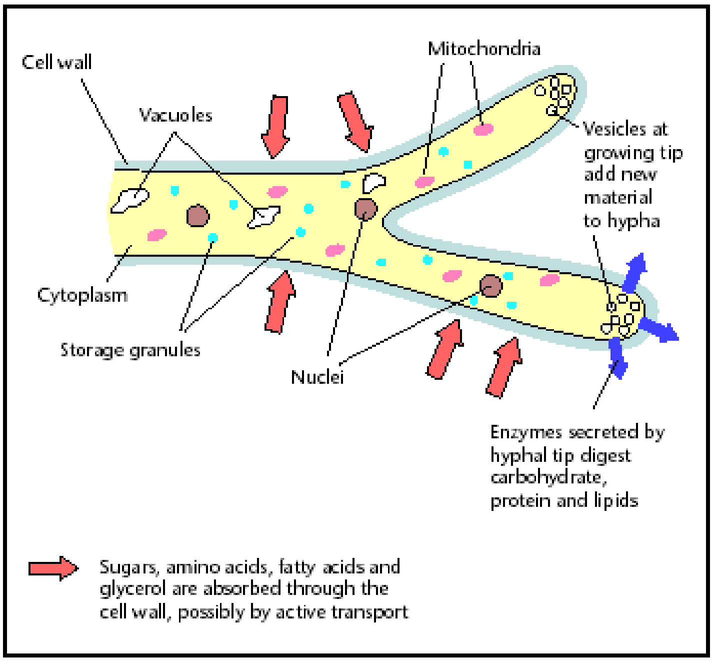
Lesson 3 – Nitrogen Cycle

Notes:

Nitrogen is one of the essential elements required for life along with carbon, hydrogen and oxygen. Without nitrogen animals could not make amino acids and therefore proteins which are essential for production of new cells and enzymes. Without access to nitrogen the nitrogenous bases required to make nucleotides would also prevent the replication of DNA and RNA.

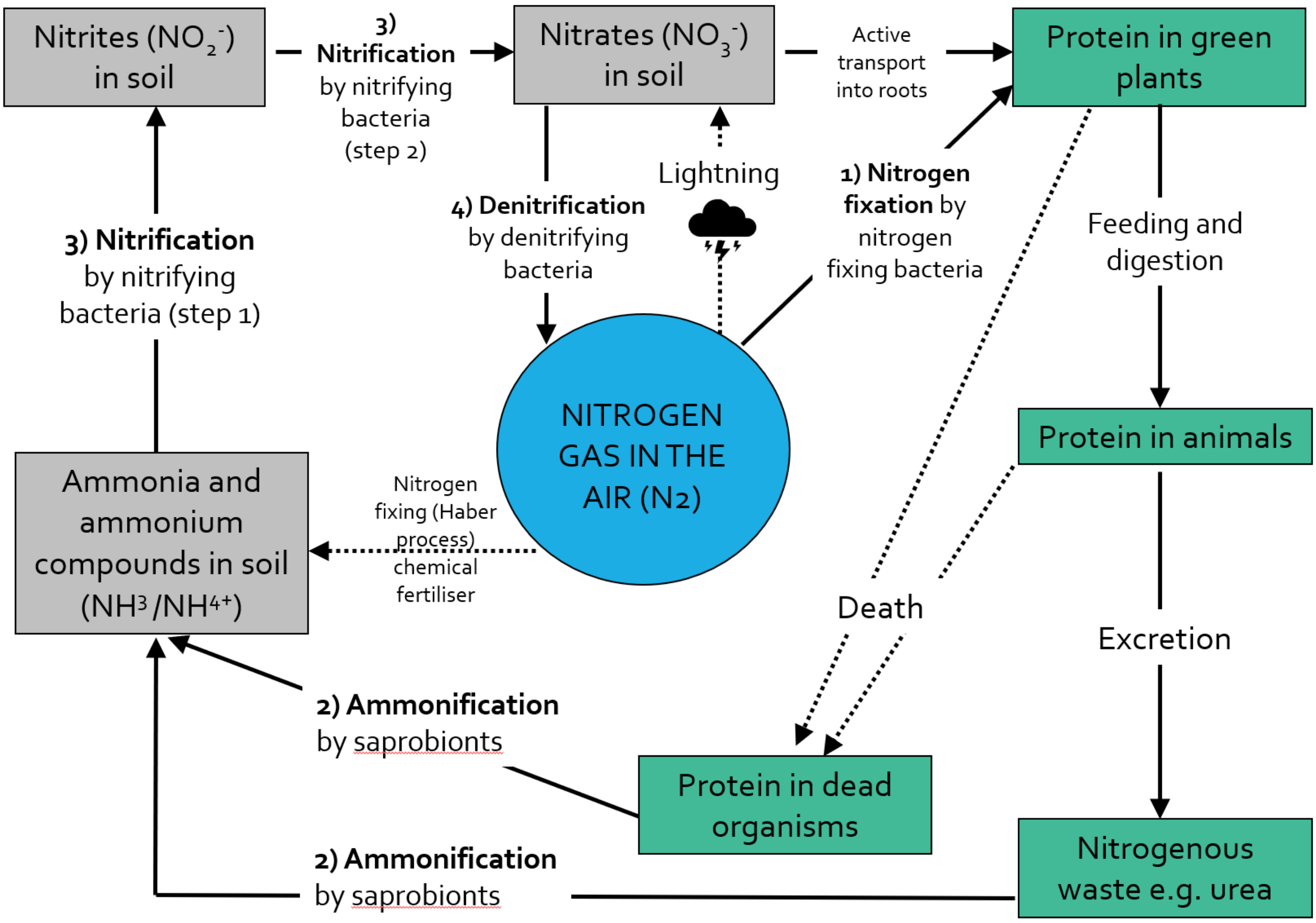
Nitrogen is abundant in the atmosphere as N_2 gas (~78%) but this gas is very unreactive so it must be 'fixed' through a reaction with hydrogen into ammonium compounds which are more accessible and useful to organisms. Plants extract nitrogen from the soil in nitrates which they actively transport into their roots. Animals access nitrogen by eating plants and other animals and hydrolysing the proteins to amino acids in digestion which can then be used in translation to make new proteins. When organisms die, their proteins are broken down by special decomposers in the soil called saprobionts.

Saprobionts are a group of microorganisms (bacteria and fungi) which feed on the remains of dead plants and animals and their waste (faeces and urine) which is known as **saprobiotic nutrition**. They are a type of decomposer which allows chemical elements in the remains to be recycled. They secrete enzymes which break down organic molecules which they then absorb – this is known as **extracellular digestion** (as it happens outside of the organism).



The rest of the nitrogen cycle is carried out by specialised bacteria which live in the soil/water or inside specialised plant root structures as part of a symbiotic relationship. There are three more stages and each is carried out by a different group of bacteria:

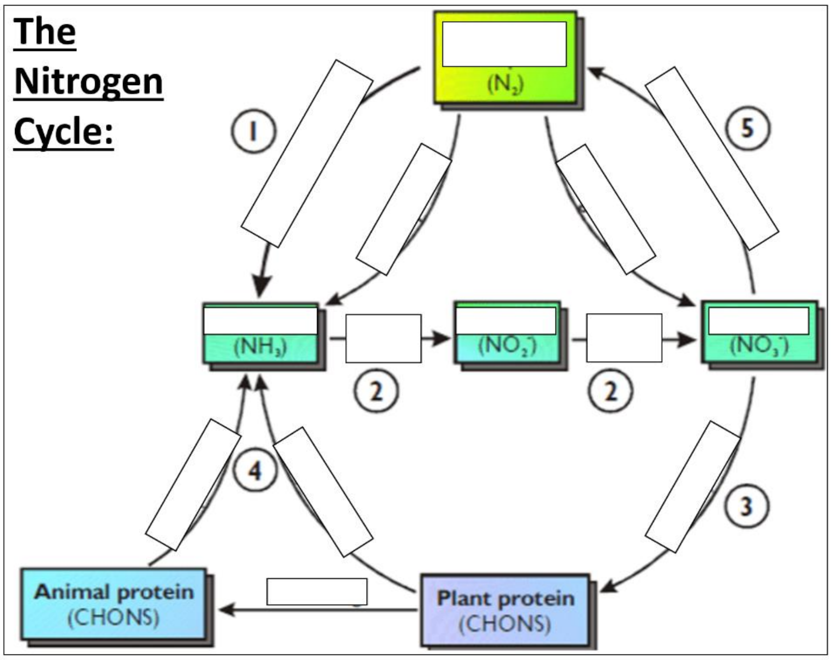
Stage	Organism	What happens
1) Nitrogen Fixation	Nitrogen fixing bacteria e.g *Rhizobium*	Nitrogen gas is reduced by adding H_2 to form ammonia. It is catalysed by the nitrogenase enzyme in bacteria which live in soil/water or in plant roots. Leguminous plants (such as peas, beans and clovers) have a mutualistic association with bacteria that live in structures called root nodules. The bacteria get sugars in return for ammonium compounds
2) Ammonification	Saprobionts	Break down amino acids in organic matter (dead organisms and excreted waste) and convert them into ammonium compounds (NH^3) which form ammonium ions in soil (NH^{4+})
3) Nitrification	Nitrifying bacteria	Ammonium compounds are converted to nitrates (oxidised). It takes place in two stages, and different species of bacteria are involved at each stage. Energy is released in reactions and bacteria use this to carry out chemosynthesis.
4) Denitrification	Denitrifying bacteria	Nitrates are converted into nitrogen gas by bacteria in anaerobic conditions. They use nitrate ions as electron acceptors for respiration instead of oxygen which produces nitrogen gas. Nitrogen gas is released into the atmosphere. This reduces the amount of nitrates in the soil. Ploughing or aerating soil can increase the oxygen in the soil and reduce denitrification as it only happens in anaerobic conditions.



Nitrogen fixation also occurs when lightning causes nitrogen to be oxidised and form nitrates which end up in soil and in the Haber process which is used to produce large amounts of chemical nitrogen fertiliser.

Recall Questions:

1. Name the two main uses of nitrogen in organisms
2. Where is the main source of nitrogen in the nitrogen cycle?
3. Name two types of saprobiont
4. Describe saprobiotic nutrition
5. What stage of the nitrogen cycle is carried out by saprobionts and why is it necessary?
6. Describe and explain the relationship of Rhizobium bacteria and plants
7. What occurs in nitrification?
8. What stage returns nitrogen to the atmosphere?
9. What other processes fix nitrogen?
10. Complete the diagram:



Exam Questions

Q1. Mammals and fish remove nitrogenous waste from their bodies in different forms.

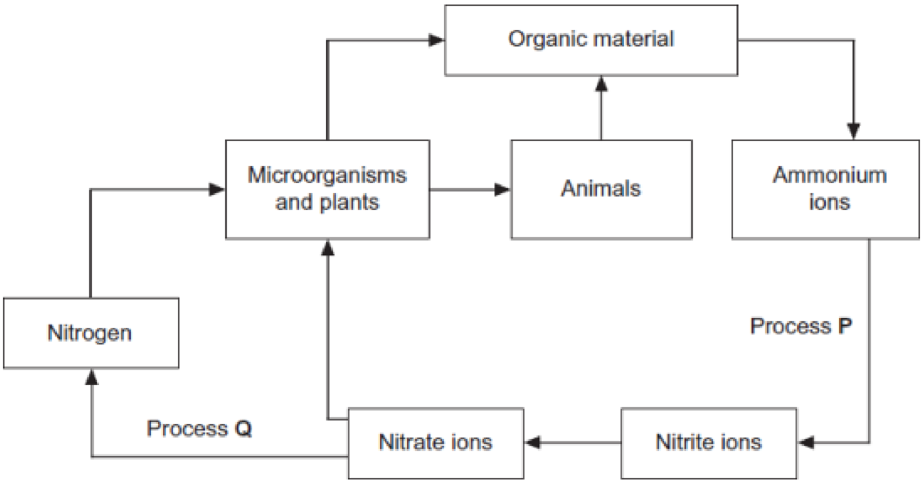
(a) Name **two** polymers present in mammals and fish that contain nitrogen.

1. ______________________________

2. ______________________________

(2)

Q2. The diagram shows the nitrogen cycle.



(a) (i) Name process **P**.

______________________________ **(1)**

(ii) Name process **Q**.

______________________________ **(1)**

(b) Leguminous crop plants have nitrogen-fixing bacteria in nodules on their roots.
On soils with a low concentration of nitrate ions, leguminous crops often grow better than other types of crop. Explain why.

____

____

____

____

______________________________ **(2)**

(c) Applying very high concentrations of fertiliser to the soil can reduce plant growth. Use your knowledge of water potential to explain why.

____

____

____

______________________________ **(2)**

Q2. Nitrogenase catalyses the reduction of nitrogen during nitrogen fixation. The reaction requires 16 molecules of ATP for each molecule of nitrogen that is reduced.

(a) Nitrogen gas is the usual substrate for this enzyme. Name the product.

___

(1)

(b) Nitrogenase also catalyses reactions involving other substances. Explain what this suggests about the shapes of the molecules of these other substances.

___

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___

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___

(2)

(c) (i) *Azotobacter* is a nitrogen-fixing bacterium. It produces the enzyme nitrogenase. The enzyme only works in the absence of oxygen.

Azotobacter has a very high rate of aerobic respiration compared with bacteria that do not fix nitrogen. Suggest **two** advantages of the very high rate of aerobic respiration.

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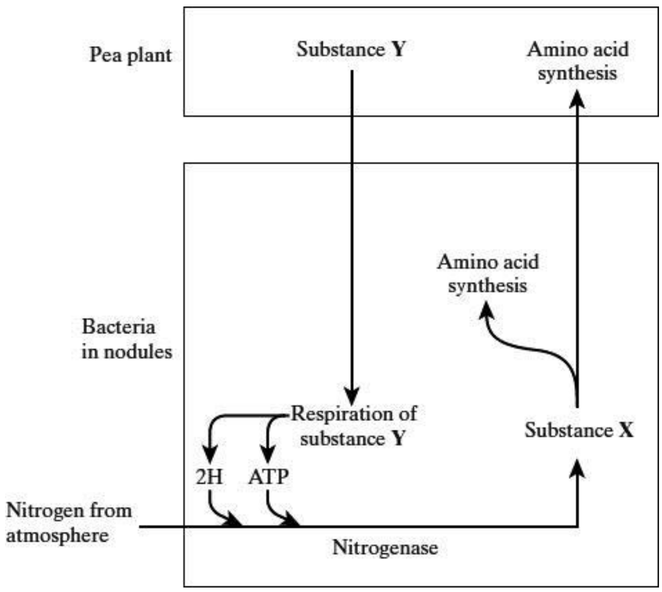
(2)

Q3. Pea plants are leguminous and have nodules on their roots which contain bacteria that are able to fix nitrogen. The diagram shows some of the processes involved in nitrogen fixation by these bacteria.



(a) Name

(i) substance **X**;

____ **(1)**

(ii) substance **Y**.

____ **(1)**

(b) Pea plants respire aerobically, producing ATP which can be used for amino acid synthesis. Describe the role of oxygen in aerobic respiration.

____

____

____

____ **(2)**

(c) The bacteria respire anaerobically. This produces hydrogen and ATP used in nitrogen fixation. The hydrogen comes from reduced NAD. Explain how the regeneration of NAD in this way allows ATP production to continue.

____

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____ **(2)**

(d) The enzyme nitrogenase is specific to the reaction shown. Explain how **one** feature of the enzyme would contribute to this specificity.

Feature

____

Explanation

____

____

____ **(2)**

(e) Sodium ions act as a non-competitive inhibitor of the enzyme nitrogenase. Explain how the presence of a non-competitive inhibitor can alter the rate of the reaction catalysed by nitrogenase.

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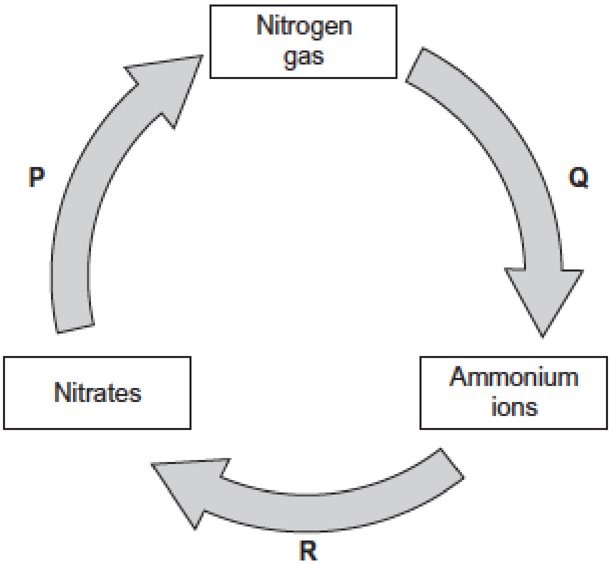
____ **(3)**

Q4. The diagram shows part of the nitrogen cycle.



(a) Which **one** of the processes **P**, **Q** or **R** involves nitrification?

☐

(1)

(b) The diagram above includes one process in which microorganisms add ammonium ions to soil.

Describe another process carried out by microorganisms which adds ammonium ions to soil.

___

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___

___

___ **(2)**

(c) Denitrification requires anaerobic conditions. Ploughing aerates the soil.
Explain how ploughing would affect the fertility of the soil.

___

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(2)

Q5. (b) Describe how the action of microorganisms in the soil produces a source of nitrates for crop plants.

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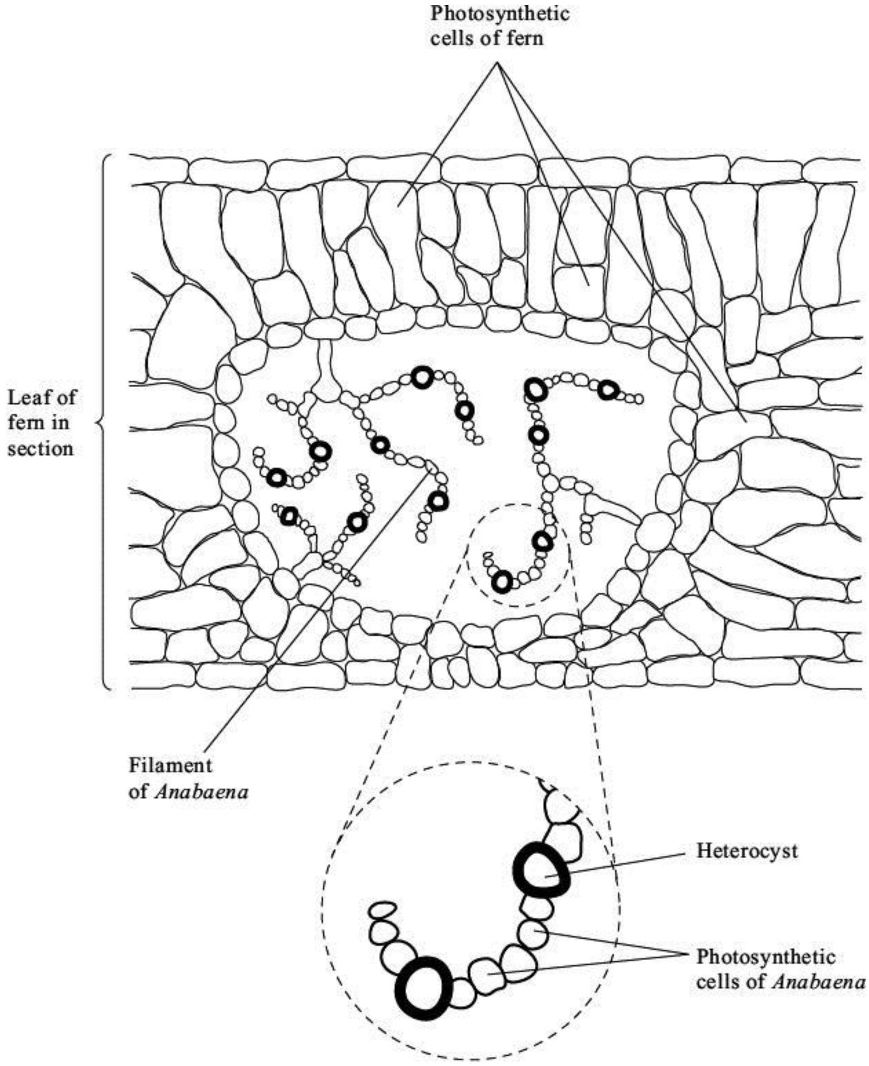
____ **(5)**

Q2. (b) Anabaena is a prokaryote found inside the leaves of a small fern. Anabaena can produce ammonia from nitrogen (nitrogen fixation). This reaction only takes place in the anaerobic conditions found in cells called heterocysts. Heterocysts are thick-walled cells that do not contain chlorophyll. The drawing shows the relationship between *Anabaena* and the fern.



(i) Suggest how the features of the heterocysts improve the efficiency of the process of nitrogen fixation.

____

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(3)

(ii) In China, the fern is cultivated and ploughed into fields to act as an organic fertiliser. Explain how ploughing the fern plants into the soil results in an improvement in the growth of the rice crop grown in these fields.

____

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(5)

Homework

Complete the sentences using the words in bold

aerobic amino acids ammonia ammonification anaerobic ATP bacteria bacteria broken down carbohydrates cleaner competition composition decomposing dies diversity DNA eutrophication farming fertilisers fish food chain free-living Haber harvested inorganic light lightning mutualistic nitrate nitrogen-fixing nucleic acids oxygen photosynthesise ponds productivity proteins replenish respiration rivers RNA soluble urea waterlogged

Plants and animals need nitrogen to synthesise none essential __________ _________ (to make ____________) and ______________ ________ (to make _______, _______ and ______). As with carbon, the ultimate source of nitrogen in the _________ _________ is from the atmosphere via plants, however, although the atmosphere is 78% nitrogen (N_2), plants can't use it in that form. Instead they need _____________ to convert it into usable nitrogen compounds first.

1. Nitrogen fixation
   - _____________ bacteria, found in root nodules of leguminous plants (peas, beans), can fix nitrogen into ____________ (NH_3) which can then be converted into other nitrogenous compounds and used directly by the plant (in return the plants provides the bacteria with ______________)
   - Alternatively, free-living ___________-__________ bacteria can convert atmospheric gas into _____________ which then undergoes nitrification. This process normally happens under ________________ conditions
   - Nitrogen fixation can also happen spontaneously when _____________ passes through the atmosphere, again this will then undergo nitrification
   - Nitrogen fixation can also be conducted artificially on an industrial scale. The _______ process produces ammonia from atmospheric nitrogen to make fertilisers

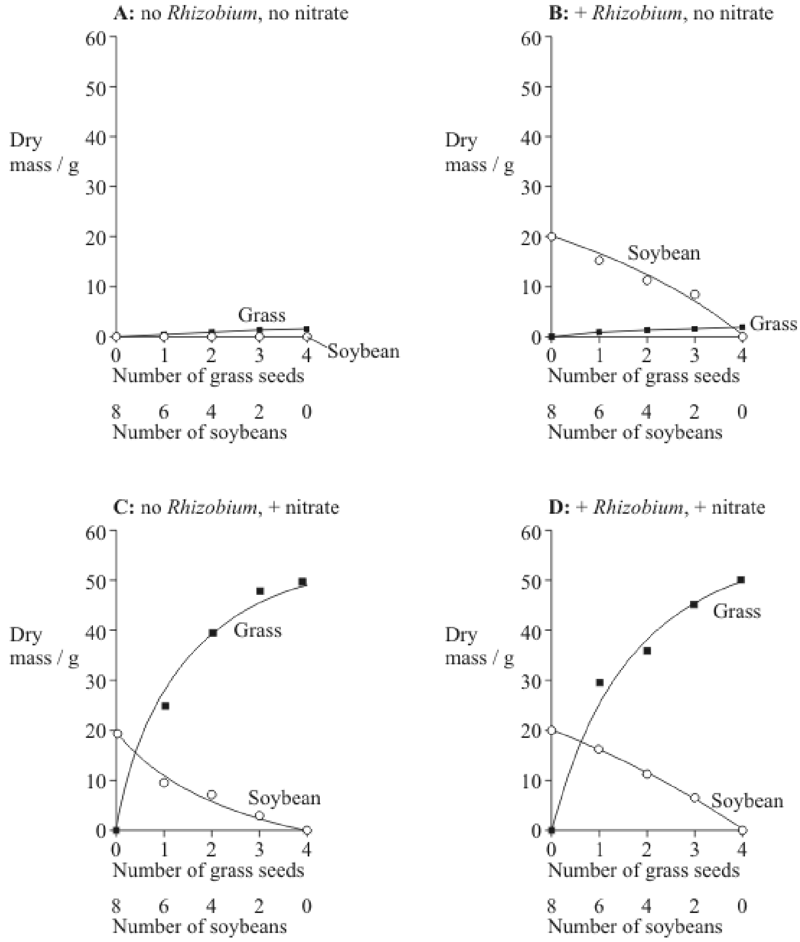
2. Ammonification
   - Nitrogen compounds from dead organisms are turned into ammonia by _____________ bacteria
   - Animal waste also contains compounds (such as ________) that are turned into ammonia

3. Nitrification
   - This is the conversion of ammonia into _________ ions by nitrifying bacteria, which can then be used by the plant - the ammonia comes either from nitrogen fixation by _______-__________ nitrogen-fixing bacteria or ________________ by decomposing bacteria
   - Firstly, certain species of nitrifying bacteria synthesise __________ (NO_2^-) from ammonia
   - Secondly, other species of nitrifying bacteria convert the nitrite into to ___________ (NO_3^-)
   - This process requires oxygen so _____________ conditions are essential. Nitrification is therefore most efficient in soil with lots of air spaces by ploughing and good drainage

4. Denitrification
   - Nitrates in the soil may be converted back into nitrogen gas by ______________ bacteria before they are used by the plants
   - These bacteria use the nitrates to carry out ______________ and produce nitrogen gas. This happens under anaerobic conditions such as in ________________ soil.

Answer the exam questions

Q1. The soybean is a leguminous plant. The effect of nitrate fertiliser and of the nitrogen-fixing bacterium, Rhizobium, on the growth of soybeans and on the growth of one species of grass was investigated. The soybeans and grass seeds were sown together in pots of soil in five different proportions. They were then treated with different combinations of nitrate fertiliser and Rhizobium bacteria. The dry masses of the soybean plants and of the grass were determined after 6 months of growth. The results are shown in the graphs.



(a) Did Rhizobium bacteria have any effect on the growth of the grass? Give evidence from graphs C and D for your answer. [1]

....

....

(b) Can the soybean make use of nitrogen supplied in the form of nitrate fertiliser? Give evidence from the graphs for your answer. [2]

....

....

(c) Describe and explain the effect of Rhizobium bacteria on the growth of soybeans. [3]

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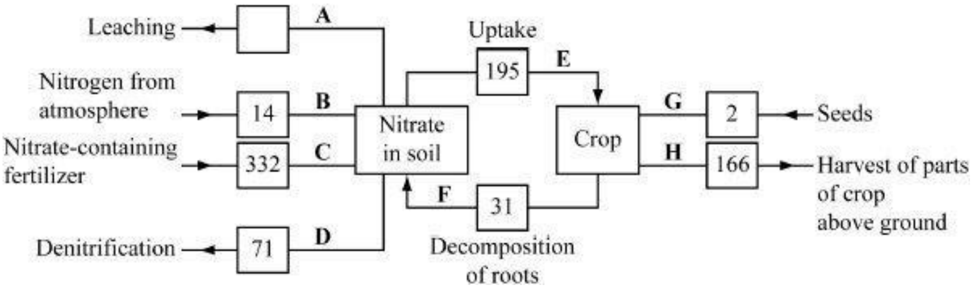
Q2. A wheat crop was grown in a field on a Dutch farm. When the wheat was harvested, all parts of the crop growing above ground were removed. The diagram shows the nitrogen cycle for this field. The figures are in kg of nitrogen per hectare per year.



(a) Give the letter of one pathway involving

(i) nitrifying bacteria. [1]

....

(ii) nitrogen-fixing bacteria. [1]

....

(b) (i) Describe the part played by bacteria in pathway D. [2]

....

....

....

(ii) This wheat crop was growing on clay soil. Clay is easily waterlogged. The figure for pathway D would be lower on a farm with sandy soil that does not become waterlogged. Explain why. [2]

....

....

....

(c) (i) Calculate the maximum amount of nitrogen that could be leached from the soil where this crop was growing in a year. [1]

Answer..............................kg ha–1

(ii) The information in the diagram could be useful to the farmer in reducing leaching. Explain one way in which it could be useful. [1]

....

....

(d) It is estimated that, each year, a total of 3 × 109 tonnes of ammonia are converted to nitrate. Only 2 × 108 tonnes of ammonia are produced from nitrogen gas. Explain the difference in these figures. [2]

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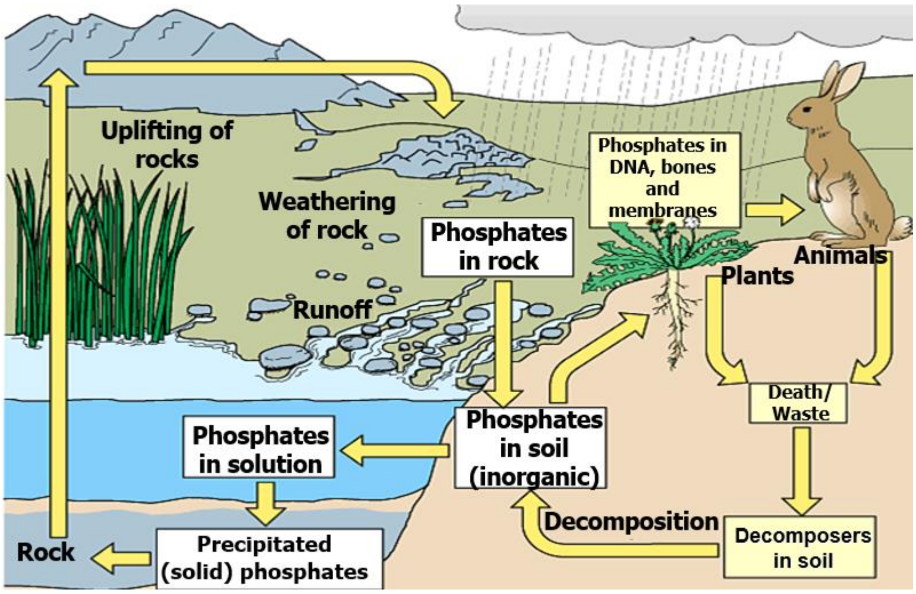
Lesson 4 – The Phosphorous Cycle

Notes:



Phosphorous is another essential nutrient. It is required to make the phosphate backbone of DNA, to make ATP, for phospholipids in cell membranes and as calcium phosphate to make bones in animals.

The soil and anything that grows on it will contain phosphate. The phosphorous cycle is slow and phosphorous tends to be a limiting nutrient as it is found in low concentrations, particularly in aquatic systems – this means it can limit the growth of plants and animals. This is because without phosphorous there would be less ATP so less energy for growth, less DNA and mRNA in order to produced proteins required for growth, and less phospholipids for producing cell membranes. It is also required in stages of photosynthesis e.g regenerating RuBP so it can slow that down too.

Most phosphorous exists as the phosphate ion PO_4^{3-} in sedimentary rocks, it is released when the rocks weather slowly over time where it leaches into water and soils. Phosphate is transferred from the soil into plants through active transport in the roots.

As with nitrates, plants often form a symbiotic relationship with a fungus that helps them to obtain more phosphate from the soil in return for sugars from photosynthesis. These microorganisms are known as mycorrhizal fungi or mycorrhizae. The hyphae of the fungus increase the surface area of the plants root system, this allows them to obtain more phosphate, nitrates and water from the soil than plants without the association.

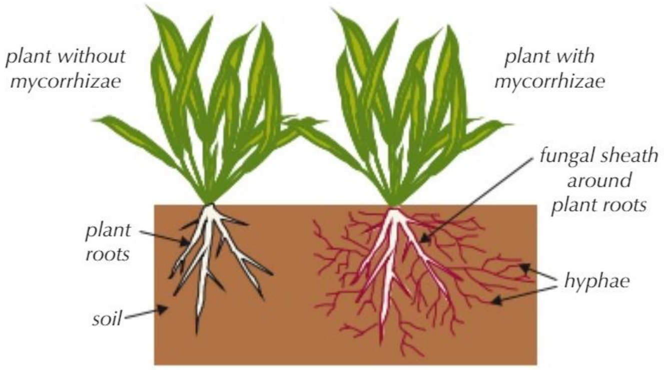
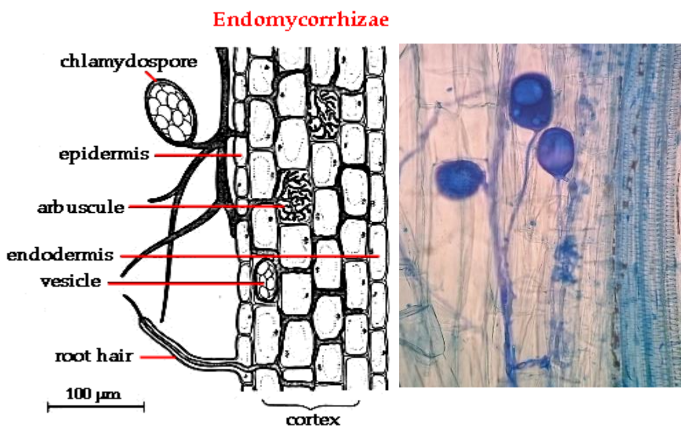


Figure 1: A plant without mycorrhizae (left) and with mycorrhizae (right).



Phosphate in lakes and rivers is taken up by aquatic producers such as algae. Phosphate is transferred between organisms thorough the process of feeding by either herbivore and omnivore animals. When animals and plants die or excrete waste (faeces and urine) saprobionts again break down the organic molecules and release phosphates back into the soil to be taken up again by plants. One major source of phosphate in waste comes from sea birds in the form of guano, it returns large amount of phosphates to soils in coastal areas and can be used as a natural fertilizer.

Recall Questions

1. What is phosphorus required for in organisms?
2. Why is phosphorous a limiting factor?
3. What is the main source of phosphorous?
4. How is phosphorous released slowly into the soil and waterways.
5. What are mycorrhizas?
6. How do mycorrhizae improve the growth of plants?
7. Describe the role of saprobionts in the phosphorous cycle
8. What is guano?
9. Why is guano important to the phosphorous cycle?
10. Figures A and B show simplified versions of the nitrogen and phosphorous cycles

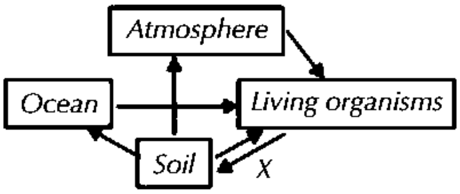


Figure A

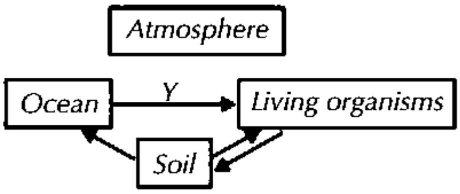
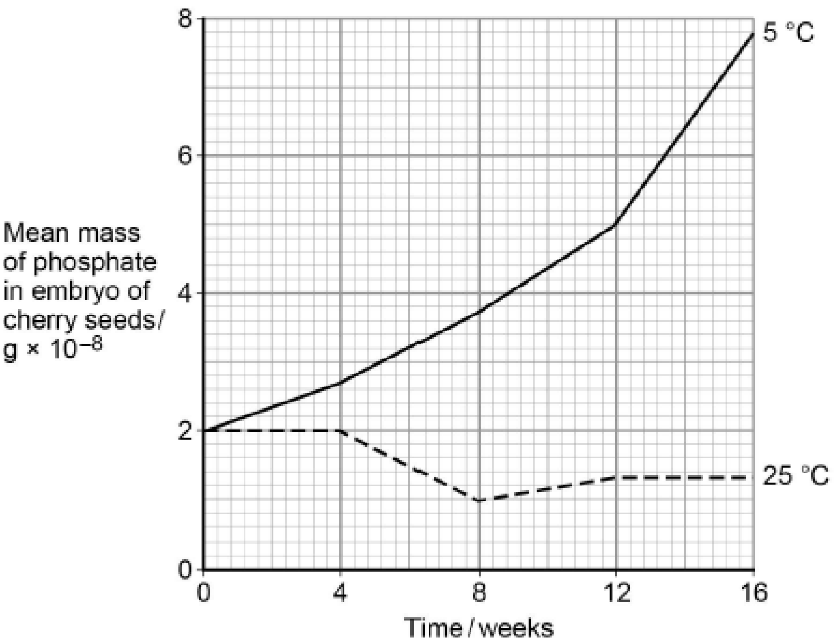


Figure B

   a. Which figure represents the phosphorous cycle?
   b. In what form is phosphorous taken up by plants?
   c. What process is happening at X on figure A?
   d. Explain what is happening at Y on figure B
   e. Give two ways in which phosphate ions are returned to the soil from living organisms.

Exam Questions

Q1. The seeds of some plant species require chilling (exposure to low temperatures) before the embryos they contain grow into plants. During chilling, storage molecules in the seed that contain phosphate are broken down and phosphates are transported to the embryo. Scientists investigated the change in the mass of phosphate in the embryos of cherry seeds exposed to two different temperatures for 16 weeks. The following graph shows their results.



(a) Phospholipids are one of the storage molecules found in cherry seeds.

Name the type of reaction used to break down phospholipids to release phosphate.

____ **(1)**

(b) The scientists concluded that an increase in phosphate in the embryo was linked to growth of the embryo.

Suggest **two** reasons why an increase in phosphate can be linked to growth of the embryo.

1. ____

____

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2. ____

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(2)

(c) Calculate the ratio of the mean mass of phosphate found at 5 °C to the mean mass of phosphate found at 25 °C after 9 weeks of chilling.

Ratio = ____________________

(1)

(d) The chilling requirement of seeds of certain plant species is considered to be an adaptation for survival in countries with seasonal changes in environmental conditions.

Suggest how this adaptation may enable these plant species to survive and respond to seasonal changes.

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(3)

Q2. Arbuscular mycorrhiza fungi (AMF) are fungi which grow on, and into, the roots of plants. AMF can increase the uptake of inorganic ions such as phosphate.

(a) Suggest **one** way in which an increase in the uptake of phosphate could increase plant growth.

____

____ **(1)**

(b) Suggest **one** way in which AMF may benefit from their association with plants.

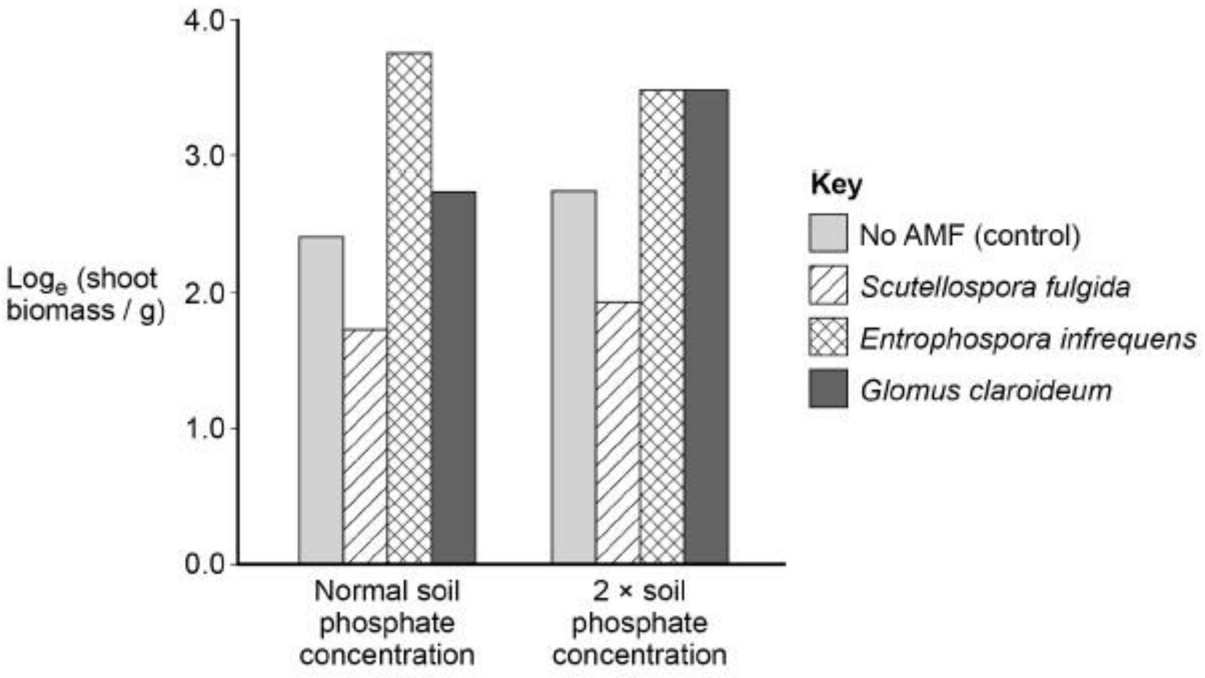
____

____ **(1)**

(c) Scientists investigated the effects of different AMF species on the productivity of the plant community of a prairie grassland ecosystem when growing in/on soil containing different phosphate concentrations.

The scientists set up identical plots of prairie grassland soil containing seeds of the plant species found in the ecosystem. The scientists added different AMF species and different concentrations of phosphate to particular plots. Control plots without AMF species were also set up. After 20 weeks the scientists determined the shoot biomass for each plot.

The results the scientists obtained are shown in the graph.



Explain why an increase in shoot biomass can be taken as a measurement of **net** primary productivity.

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____ **(2)**

(d) Using the data from the graph in part (c), evaluate the effect on plant productivity of adding AMF species and adding phosphate to the soil.

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____ **(4)**

(e) Using the e^x button on your calculator, determine the rate of shoot biomass production in grams per day for the control plot in soil with normal phosphate concentration.

Answer = ____________________ g day^{-1} **(2)**

Q3. Read the following passage.

Plants require phosphate ions that they get from soil. These ions are often in poor supply and this results in poor growth of the plants. Most plants have mycorrhizae that help the plants to obtain nitrates. Mycorrhizal networks can connect the roots of plants growing next to each other. The use of fertilisers containing phosphate and nitrates in farming inhibits the growth of mycorrhizae. As a result, intensively farmed crop plants do not have mycorrhizae.

Plants can defend themselves by producing defensive enzymes that destroy pathogens such as bacteria. Some plants express the genes for defensive enzymes in response to signal proteins secreted by other plants that are being attacked by a pathogen. These signal proteins can be released into the air.

Scientists have discovered that tomato plants increase production of defensive enzymes if plants next to them become infected with a pathogen. These tomato plants were connected by a mycorrhizal network that can carry signal proteins between them. The largest increase in defensive enzyme secretion that the scientists found in a tomato plant in response to the signal protein was by 122.6 per cent.

Use the information in the passage and your own knowledge to answer the following questions.

(a) Suggest and explain **two** reasons why a poor supply of phosphate ions results in poor growth of plants (lines 1–2).

1. ____

____

2. ____

____ **(2)**

(b) Suggest how defensive enzymes produced by plants destroy bacteria (lines 8–9).

____

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____ **(2)**

(d) Suggest and explain **the** advantage to tomato plants of transmitting signal proteins through mycorrhizal networks, rather than releasing them into the air (line 11–12 and lines 14–16).

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____ **(2)**

(e) The largest increase in defensive enzyme secretion that the scientists found in a tomato plant in response to the signal protein was by 122.6 percent (lines 16–18).

The rate of secretion of the defensive enzymes before the signal protein was produced was 450 µmol dm^{-3} g^{-1} $hour^{-1}$.

Calculate the rate of secretion **per second** after the response to the signal protein.

Answer = ____________________________ µmol dm^{-3} g^{-1} $second^{-1}$ **(2)**

(f) A student who read this passage concluded that farmers should **not** use fertilisers to increase yields when growing tomato plants.

Evaluate his conclusion.

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____ **(4)**

Q4. Scientists investigated the effect of a mycorrhizal fungus on the growth of pea plants with a nitrate fertiliser or an ammonium fertiliser. The fertilisers were identical, except for nitrate or ammonium.

The scientists took pea seeds and sterilised their surfaces. They planted the seeds in soil that had been heated to 85 °C for 2 days before use. The soil was sand that contained no mineral ions useful to the plants.

(a) Explain why the scientists sterilised the surfaces of the seeds and grew them in soil that had been heated to 85 °C for 2 days.

___

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(2)

(b) Explain why it was important that the soil contained no mineral ions useful to the plants.

___

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(1)

The pea plants were divided into four groups, **A**, **B**, **C** and **D**.

- **Group A** – heat-treated mycorrhizal fungus added, nitrate fertiliser
- **Group B** – mycorrhizal fungus added, nitrate fertiliser
- **Group C** – heat-treated mycorrhizal fungus added, ammonium fertiliser
- **Group D** – mycorrhizal fungus added, ammonium fertiliser

The heat-treated fungus had been heated to 120 °C for 1 hour.

(c) Explain how groups **A** and **C** act as controls.

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(2)

After 6 weeks, the scientists removed the plants from the soil and cut the roots from the shoots. They dried the plant material in an oven at 90 °C for 3 days. They then determined the mean dry masses of the roots and shoots of each group of pea plants.

(d) Suggest what the scientists should have done during the drying process to be sure that all of the water had been removed from the plant samples.

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(2)

The scientists' results are shown in the table below.

Treatment	**Mean dry mass / g per plant (standard deviation)**	
	Root	**Shoot**
A – heat-treated fungus and nitrate fertiliser	0.40 (±0.05)	1.01 (±0.12)
B – fungus and nitrate fertiliser	1.61 (±0.28)	9.81 (±0.33)
C – heat-treated fungus and ammonium fertiliser	0.34 (±0.03)	0.96 (±0.26)
D – fungus and ammonium fertiliser	0.96 (±0.18)	4.01 (±0.47)

(e) What conclusions can be drawn from the data in the table about the following?

The effects of the fungus on growth of the pea plants.

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The effects of nitrate fertiliser and ammonium fertiliser on growth of the pea plants.

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___ **(4)**

The scientists determined the dry mass of the roots and shoots separately. The reason for this was they were interested in the ratio of shoot to root growth of pea plants. It is the shoot of the pea plant that is harvested for commercial purposes.

(f) Explain why determination of dry mass was an appropriate method to use in this investigation.

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___ **(2)**

(g) Which treatment gave the best result in commercial terms? Justify your answer.

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____ **(2)**

Homework

Read the extract and answer the following questions

1. Are mycorrhizas necessary for plant growth?
2. Are they present in both natural and agricultural ecosystem?
3. What type of relationships do mycorrhizae form with plants?
4. What type of mycorrhizas would you be most likely to find in crop plants?
5. What properties of nitrogen and phosphorus (two answers) would require plants to use mycorrhizas to obtain them?
6. Could we produce mycorrhizas in the lab?

Mycorrhizas

Mycorrhizas are symbiotic relationships between fungi and plant roots (the term means literally 'fungus root'). Perhaps more than 80% of the species of higher plants have these relationships, and so do many pteridophytes (ferns and their allies) and some mosses (especially liverworts). They are as common on crop plants (cereals, peas, tomatoes, onions, apples, strawberry, etc) as in wild plant communities, and in several cases they have been shown to be important or even essential for plant performance. As the American plant pathologist, Stephen Wilhelm, said: '...in agricultural field conditions, plants do not, strictly speaking, have roots, they have mycorrhizas'.

To a large degree, mycorrhizas seem to be symbiotic (mutualistic) relationships, in which the fungus obtains at least some of its sugars from the plant, while the plant benefits from the efficient uptake of mineral nutrients (or water) by the fungal hyphae. However, there can be circumstances in which the fungus is mildly detrimental, and others in which the plant feeds from the fungus.

Below, we consider three of the commonest types of mycorrhiza. Each of them represents a distinctive type of association.

1. Orchid mycorrhizas

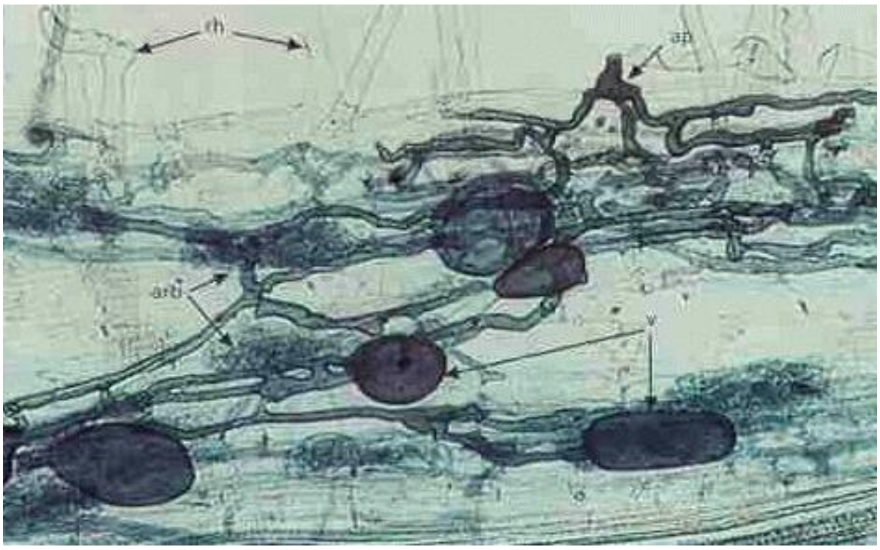
Some types of orchid are non-photosynthetic; others only produce chlorophyll when they have grown past the seedling stage. In all cases, the plant depends on sugars derived from a fungal partner for at least part of its life. The minute orchid seeds, with negligible nutrient reserves, will not germinate unless a fungus infects them.

These mycorrhizas are unusual because, in effect, the plant parasitises the fungus that invades it. They are mainly saprotrophic - they grow by degrading organic matter in soil - but they might obtain trace elements or some other factor from the plant.

2. Arbuscular mycorrhizas

Arbuscular mycorrhizas are found on the vast majority of wild and crop plants, with an important role in mineral nutrient uptake and sometimes in protecting against drought or pathogenic attack. Structures resembling those of the present-day AM fungi have been found in fossils of primitive pteridophytes of the Devonian period. It is thought that these fungi colonised the earliest land plants and that mycorrhizal associations could have been essential for development of the land flora.

The site of penetration is shown at top right, where the fungus produced a pre-penetration swelling (appressorium, ap), then it grew between the root cells and formed finely branched arbuscules (arb) and swollen vesicles (v). The arbuscules are thought to be sites of nutrient exchange - the fungus obtains sugars from the plant, and the plant obtains mineral nutrients (e.g. phosphorus) that the fungus absorbs from the soil. Vesicles are thought to be used for storage. Root hairs (rh) are also labelled.



The plant cell remains alive, because its membrane extends to encase all the branches of the fungus. Strictly speaking, therefore, the fungus is always outside of the cell, surrounded by the cell membrane. Feeding relationships of this type, in which a fungus produces special nutrient-absorbing structures within the host cells, are termed biotrophic. For further details see Biotrophic plant pathogens.

The hyphae of AM fungi extend into soil, where their large surface area and efficient absorption enable them to obtain mineral nutrients, even if these are in short supply or are relatively immobile. AM fungi seem to be particularly important for absorption of phosphorus, a poorly mobile element, and a proportion of the phosphate that they absorb has been shown to be passed to the plant.

3. Ectomycorrhizas

Ectomycorrhizas (sometimes termed ectotrophic mycorrhizas) are characteristic of many trees in the cooler parts of the world - for example pines, spruces, firs, oaks, birches in the Northern Hemisphere and eucalypts in Australia. However, some trees (e.g. willows) can have both ectomycorrhizas and arbuscular mycorrhizas, and most tropical trees have only arbuscular mycorrhizas.

Most of these fungi can be grown in laboratory culture but, unlike the wood-rotting fungi, they are poor degraders of cellulose and other plant wall materials. So they gain most of their sugars from the living plant roots in natural conditions.

Recent work has shown that several ectomycorrhizal fungi can degrade proteins (they release protease enzymes) and thus can obtain nitrogen from the decomposing leaf litter. This could be highly significant in temperate and sub-boreal forests, where the rates of mineral nutrient recycling are low because of the low microbial activity in cool, acidic conditions. Ectomycorrhizal fungi might thus play a key role in the nitrogen nutrition of trees.

Lesson 5 – Fertilisers and Eutrophication

Notes

As crops grow they take minerals from the soil and use them to grow and create biomass, in nature plants would die and decay and this would allow the nutrients to be recycled back into the soil. In agriculture the crops are harvested and removed from the field. This is also true if animals or animal products such as waste are removed to be slaughtered or transferred to different fields/grazing land.

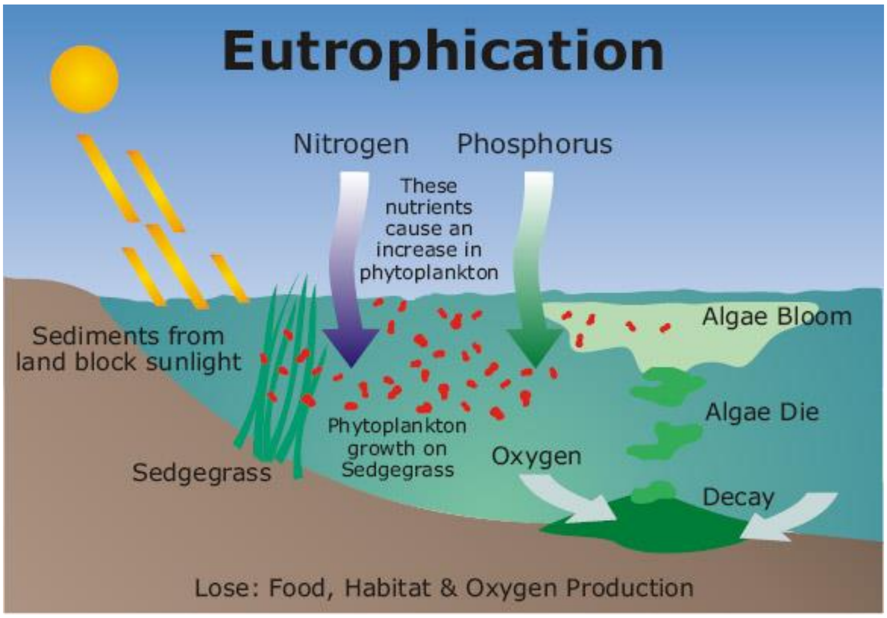
Farmers can add extra nutrients including nitrogen and phosphorous to soils to replace the nitrogen and phosphorous lost continuously in fields that are used to grow crops. This increases the productivity of the crop and improves the efficiency of energy transfer. Fertilisers can be artificial or natural:

- Artificial fertilisers – inorganic (they contain pure chemicals e.g ammonium nitrate) in the form of powder, pellets or dissolved in liquid. Ammonium nitrate is produced by the Haber process through nitrogen fixation.
- Natural fertilisers – these are produced from organic matter such as manure, composted vegetables/kitchen/garden waste, sewage slurry or parts of crops left over after harvesting.

Farmers can also use the technique of crop rotation – alternating growing crops for harvest and leguminous plants in fields. The leguminous plants will contain nitrogen fixing bacteria which will replace the nitrates lost form the soil and the plants can be left to decay to recycle other nutrients back into the soil so that is ready for the next crop.

The excess use of fertilisers can change the balance of nutrients in the soil which can cause plants to die because it reduces the water potential of the soil so water is lost by osmosis from the plants.
Soluble minerals from fertilisers can also leach into waterways and have a negative impact on aquatic environments. If the fertiliser applied is not needed by the plants it can be washed away by rain or watering systems into nearby ponds and rivers causing eutrophication:

- Excess mineral ions (nitrates and phosphates) leach into ponds or rivers.
- The large amount of nutrients causes rapid growth in algae (algal bloom)
- Large amounts of algae on the surface block light and prevent it from reaching the plants below causing them to die.
- Bacteria feed on and decompose the dead plant matter.
- Large amounts of bacteria use up the oxygen in the water to carry out respiration.
- Fish and larger aquatic organisms die because there is no longer enough oxygen in the water to survive



Eutrophication can be harmful to the natural balance of a lake and result in massive death of fish and other animals. Eutrophication is less likely with natural fertilisers as the nitrogen and phosphorous are still part of larger organic molecules which would need to be broken down by saprobionts before they are soluble and can be taken up by plants. Phosphorous is also less soluble in water than nitrates so eutrophication is more likely to be caused by nitrates.

Recall Questions

1. What are the two main nutrients lost from soil in agriculture?
2. Why are mineral ions lost from the soil in crop fields?
3. How can rotating crop plants help prevent the use of fertilisers?
4. Name three examples of natural fertiliser
5. Name a difference between natural and artificial fertilisers.
6. How can using excess fertilisers cause plants to die?
7. Why do natural fertilisers cause less leaching?
8. How do minerals from fertiliser end up in waterways?
9. What is the process that can occurs as the result of fertiliser run off?
10. Outline the steps which lead to the death of fish in ponds from excess nutrients.

Exam Questions

Q1. One farming practice used to maintain high crop yields is crop rotation. This involves growing a different crop each year in the same field.

Suggest **two** ways in which crop rotation may lead to high crop yields.

1. ____

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____

2. ____

____

____ **(2)**

Q2.

(a) Explain how including leguminous plants in a crop rotation reduces the need to use artificial fertilisers.

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____ **(2)**

(b) Application of very high concentrations of fertiliser to the soil causes plants to wilt. Explain why.

____

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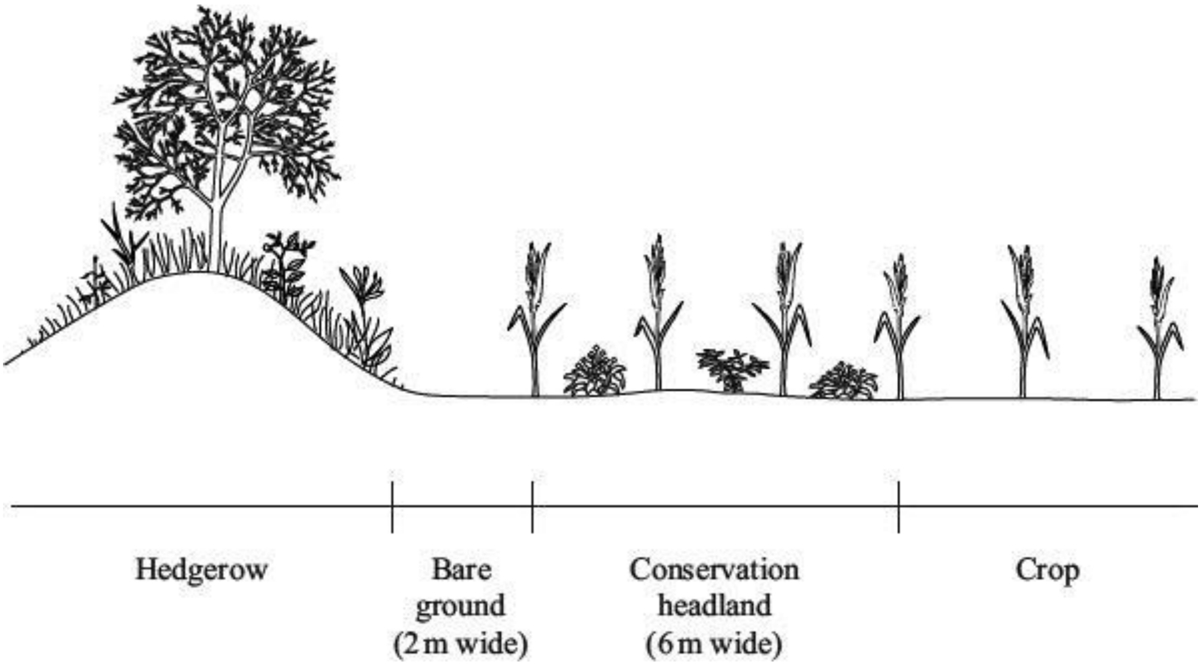
____ **(2)**

Q3. The diagram shows a hedgerow and part of a field with a crop. The land is farmed in a way that conserves wildlife. The strip of bare ground next to the hedgerow is ploughed frequently to prevent any plants from growing. The first 6 m of the field, called the conservation headland, is sprayed with a selective herbicide to control some kinds of weeds. The rest of the field is sprayed with herbicide to kill all weeds.



(a) Suggest **one** advantage of leaving a strip of bare ground between the hedgerow and the field.

____

____ **(1)**

(b) Suggest the benefit of allowing some weeds to grow in the conservation headland.

____

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____ **(2)**

(c) After harvesting the crop, the farmer digs the unwanted stems and roots into the soil. Explain how the nutrients contained in these plant parts become available for use by other organisms.

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____ **(4)**

Q4.

(a) Farmers who grow wheat sometimes leave a field fallow for a year by not growing a crop in it. The concentration of nitrate ions in the soil decreases when a field is left fallow.

(i) When grass is grown in the field, fewer nitrate ions are lost than when the field is left with bare soil. Explain why.

___

___ **(1)**

(ii) A crop of leguminous plants such as clover may be grown in the field and then ploughed in. Explain why less fertiliser would be needed for the wheat crop in the following year.

___

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___

___ **(2)**

(b) The table gives information about the yield and profitability of a wheat crop grown using different amounts of fertiliser.

Nitrogen fertiliser applied / kg ha^{-1}	**Grain yield / tonnes ha^{-1}**	**Grain protein / %**	**Value added by using fertiliser / £ha^{-1}**	**Cost of using fertiliser / £ha^{-1}**	**Benefit : cost ratio**
0	2.4	11.7	–	–	–
25	2.5	12.5	19	11	1.7 : 1.0
50	2.5	12.9	25	22	1.1 : 1.0
75	2.5	13.3	31	33	0.9 : 1.0
100	2.5	13.5	37		

(i) Describe the effects of increasing fertiliser application on the yield and protein content of the grain produced.

___

___

___

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(2)

(ii) Use the data in the table to estimate the benefit: cost ratio for a fertiliser application of 100 kg ha^{-1}. Write your answer in the table.

(1)

Q5. Farmers use artificial fertilisers to maintain or increase yield from grain-producing crop plants such as wheat.

(a) Artificial fertiliser is used to replace mineral ions removed from the land when crops are harvested. One of the mineral ions is nitrate.

Give **two** examples of biological molecules containing nitrogen that would be removed when a crop is harvested.

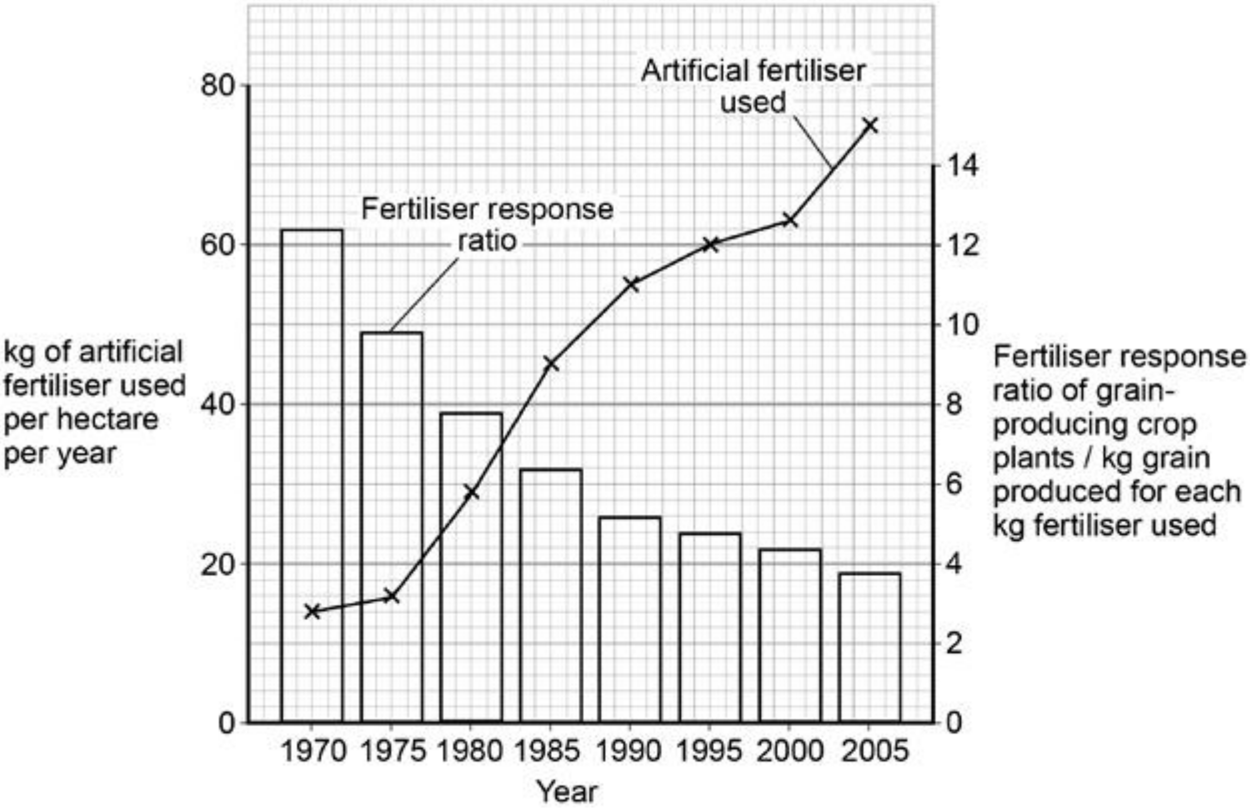
1. ____

2. ____

(2)

(b) Scientists investigated changes in the use of artificial fertiliser in India between 1970 and 2005. They also investigated changes in the **fertiliser response ratio**. This ratio shows how many kg of grain are produced for each kg of fertiliser used.

The graph shows their results in the form the scientists presented them. (A hectare is a unit of area commonly used in agriculture)



Use these data to calculate the difference in the mass of grain produced per hectare in 1970 compared with 2005.

Show your working.

Difference ____________________ kg $hectare^{-1}$

(2)

(c) Use the data in the graph above to evaluate the use of artificial fertilisers on grain-producing crops in India.

(2)

Q6. When fertilisers are applied to fields next to a lake, nitrogen-containing substances from the fertilisers get into the lake.

(a) (i) Describe how the nitrogen-containing substances get into the lake.

(1)

(ii) It takes longer for the nitrogen-containing substances to get into the lake when an organic fertiliser is used than when an inorganic fertiliser is used. Explain why it takes longer when an organic fertiliser is used.

(2)

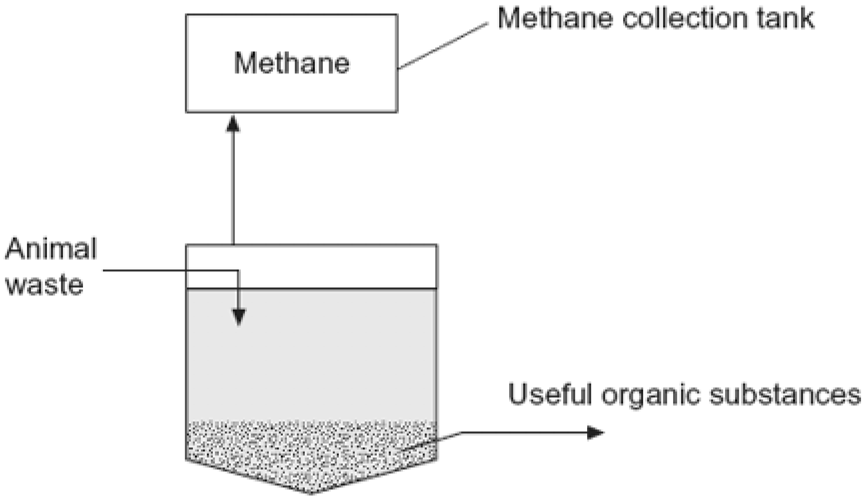
(b) Describe how the presence of nitrates in a lake may eventually lead to the death of fish.

(4)

Q7. Intensive rearing of livestock produces large quantities of waste. Some farmers use an anaerobic digester to get rid of the waste.

In an anaerobic digester, microorganisms break down the large, organic molecules in the waste. This produces methane, which is a useful fuel. It also produces organic substances that can be used as a natural fertiliser.

The diagram shows an anaerobic digester.



(a) (i) Suggest **two** advantages of processing waste in anaerobic digesters rather than in open ponds.

1. ____

____

2. ____

____

(2)

(ii) The anaerobic digester has a cooling system, which is not shown in the diagram.

Without this cooling system the digester would soon stop working. Explain why.

____

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(2)

(b) (i) The over-application of fertiliser increases the rate of leaching. Explain the consequences of leaching of fertiliser into ponds and lakes.

____

____

____

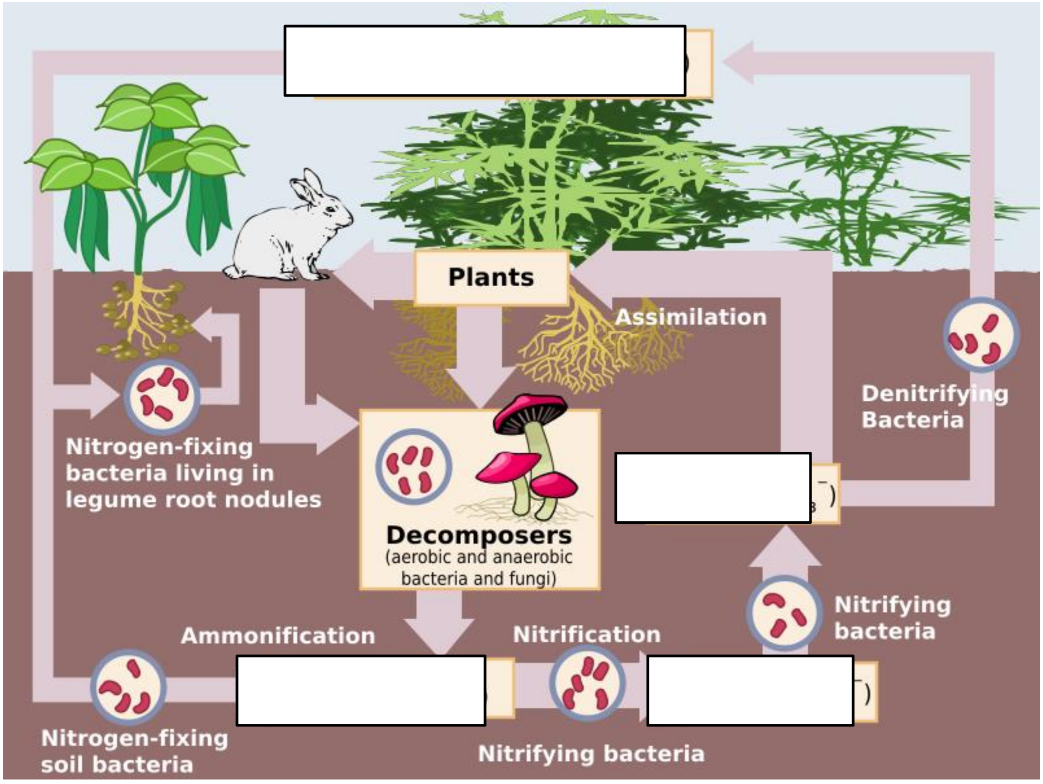
(3)

(ii) Give **one** advantage of using natural fertiliser produced in the digester rather than an artificial fertiliser.

(1)

Homework

Complete the diagram with the name and formula of the missing nitrogen compounds



Complete the sentences using the words in bold

aerobic amino acids ammonia ammonification anaerobic ATP bacteria bacteria broken down carbohydrates cleaner competition composition decomposing dies diversity DNA eutrophication farming fertilisers fish food chain free-living Haber harvested inorganic light lightning mutualistic nitrate nitrogen-fixing nucleic acids oxygen photosynthesise ponds productivity proteins replenish respiration rivers RNA soluble urea waterlogged

_______________ makes large demands on soil because mineral ions (such as nitrates) are continually being taken up by the crops. In natural ecosystems the minerals are returned when the plant ________ and is decomposed but in agricultural ecosystems the plants are _______________ and transported away for consumption (taking the mineral ions with them) and are rarely returned to the same area. This makes it necessary to ______________ the minerals or plant growth will be affected.

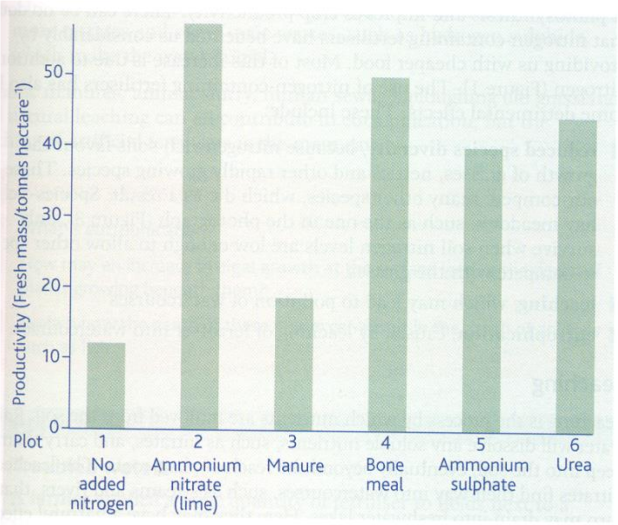
As a result, farmers use _______________ containing mostly nitrogen, phosphorus and potassium compounds. Organic (natural) fertilisers include animal ____________ (manure), composted plant matter and bone meal, while ______________ (artificial) fertilisers are mostly derived from the Haber process. Fertilising the land results in plants that develop earlier, grow taller and have a greater leaf area; collectively this increases the rate of photosynthesis and so increases _____________. Inorganic fertilisers have a number of benefits, such as having a known _________________, being _____________ to apply, being more concentrated so they are easier to transport and more immediately releasing the nutrients, but they are also more expensive and are more likely to be leached out of soils (dissolved in water and washed away) and can cause __________________.

- Nitrates leached from fertilised fields stimulate growth of algae in _________ and __________
- Large amounts of algae block _________ from reaching the plants below and plants die as they are unable to ________________
- ___________ feed on the dead plant matter and an increased numbers of bacteria reduce the _____________ concentration in water by carrying out aerobic respiration
- _________ and invertebrate organisms die as there isn't enough oxygen resulting in a significant reduction in species ______________

This occurs particularly with inorganic fertilisers because they are more _____________ than organic fertilisers and they do not need to be __________ __________ into more simple compounds.

Reduced species diversity can also occur on land since nitrogen-rich soils favour the growth of grasses, nettles and other rapidly growing species. This causes more ______________ against other species, which may then die out.

Answer the questions



The graph below represents data from an investigation in which the same crop was grown on 6 identical plots of land, in the same area. The land was treated with 5 types of fertiliser at a controlled application rate of 140kg total nitrogen per hectare.

1. Which forms of nitrogen used in the investigation were "natural fertilisers"? [1]

....

2. What was the purpose of plot 1? [1]

....

3. Suggest why added nitrogen increased productivity irrespective of the form it was added. [2]

....

....

4. The actual mass of each fertiliser added was different. Explain why. [2]

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....

5. Fertiliser manufacturers often claim that nitrogen added in the form of ammonium salts increases crop productivity better than other forms of fertiliser. State whether or not this experiment supports this claim. [3]

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6. Two fields, A and B, were used to grow the same crop. The fields were divided into plots. Different masses of fertiliser containing sodium nitrate were applied to these plots. After six weeks, samples of crop plants from each plot were collected and their mass determined. The results are shown in the table.

Mass of fertiliser added/kg ha^{-1}	**Mass of crop/kg m^{-2}**	
	Field **A** - used for grazing cattle in previous year	Field **B** - used for same crop in previous year
0	14.5	6.4
10	16.7	9.8
20	17.4	12.9
30	17.5	16.2
40	17.5	17.1
50	17.5	17.1
60	17.5	17.1

(a) (i) Describe the pattern shown by the data for field B. [1]

....

....

(ii) Explain the change in the mass of crop produced from field B when the mass of fertiliser added increases from 0 to 20 kg ha–1. [2]

....

....

....

(iii) Explain why the mass of crop produced stays the same in both fields when more than 40 kg of fertiliser is added. [2]

....

....

....

(b) In the previous year, field A had been used for grazing cattle. Field B had been used to grow the same crop as this year. When no fertiliser was added, the mass of crop from field A was higher than from field B. Explain this difference. [2]

....

....

....

(c) Explain two advantages and one disadvantage of an inorganic fertiliser such as sodium nitrate compared with an organic fertiliser such as manure. [3]

Advantage 1: ....

Advantage 2: ....

Disadvantage: ....

Section Summary

Make sure you know...

- That plants make organic compounds during photosynthesis using light energy from the Sun and carbon dioxide from the atmosphere (in land-based ecosystems) and dissolved in water (in aquatic ecosystems).
- That some of the sugars produced during photosynthesis are used immediately for respiration.
- That the rest of the sugars are used to make biological molecules — these form the plants' biomass.
- That a plant's biomass is the mass of living material or the chemical energy that is stored in the plant.
- That biomass can be measured in terms of the mass of carbon that an organism contains or the dry mass of its tissue per unit area.
- That dry mass is the mass of an organism with the water removed and that the mass of carbon is approximately 50% of the dry mass.
- That the chemical energy stored in an organism can be estimated using a calorimeter.
- That the gross primary production (*GPP*) is the total amount of chemical energy that is converted from light energy by plants during photosynthesis, in a given area.
- That the energy lost to the environment as heat when plants respire is called the respiratory loss (*R*).
- That the net primary production (*NPP*) is the energy remaining from *GPP* after respiratory loss and that this is shown by the formula $NPP = GPP - R$.
- That when primary production is expressed as a rate it is called primary productivity.
- That *NPP* is the energy available for a plant's growth and reproduction and is also the energy available to the next trophic level.
- That consumers also store energy as biomass.

- That about 90% of the energy available to consumers is lost to the environment — some is not ingested (e.g. roots, bones), some is indigestible and is egested as faeces, and some is lost through respiration or the excretion of urine.
- That the remaining energy or net production (*N*) of consumers can be calculated using the following formula: $N = I - (F + R)$, where *I* is the chemical energy in ingested food, *F* is the chemical energy lost in faeces and urine and *R* is the energy lost through respiration.
- That when net production of consumers is expressed as a rate it can be called net or secondary productivity.
- That food chains and webs show how energy is transferred through an ecosystem.
- That farming practices try to maximise production by simplifying food webs to reduce energy losses (e.g. by removing pests using pesticides or biological agents) and by reducing respiratory losses (e.g. by limiting the movement of livestock and keeping livestock warm).
- That microorganisms such as bacteria and fungi are saprobionts and recycle nutrients through food webs through the decomposition of dead plants and animals and waste matter.
- That some fungi form symbiotic relationships with plants known as mycorrhizae, and that these increase the rate of water and mineral ion uptake by plants by increasing the surface area of the plants' root system.
- The role of microorganisms in the four main processes of the nitrogen cycle: nitrogen fixation, ammonification, nitrification and denitrification, including the role of saprobionts.
- How phosphorus is recycled in natural ecosystems, including the role of mycorrhizae.
- That natural and artificial fertilisers are used to replace the nitrates and phosphates that are lost from the soil when crops are harvested or livestock are removed from the area.
- That leaching is when water soluble compounds in the soil are washed away, e.g. by rain.
- That the leaching of fertilisers can cause eutrophication.
- That eutrophication involves the rapid growth of algae, causing plants to die from lack of light, and that bacteria feeding on the dead organic matter decrease the oxygen concentration causing other aquatic organisms to die as well.