Bio Factsheet

April 2001 Number 90

Answering Questions on Nutrient Cycles

This Factsheet summarises the facts and concepts that are commonly tested on AS and A2 papers.

AS and A2 syllabus content on nutrient cycles:

- **Stages of the water cycle.**
- **Stages of the carbon cycle, including the roles of microorganisms, carbon sinks and carbonates in the cycle.**
- **Stages of the nitrogen cycle, including the roles of microorganisms as illustrated by decomposers/deaminators, nitrifying bacteria (Nitrosomonas, Nitrobacter), nitrogen fixing bacteria (Rhizobium, Azotobacter), and denitrifying bacteria (Pseudomonas, Thiobacillus).**
- **How the carbon and nitrogen cycles are disrupted by human activities.**

(Edexcel specify the names of bacteria as listed above, but OCR, AQA and Welsh Board syllabuses do not specify named bacteria

The Carbon Cycle

Examiners expect you to know more about the carbon cycle than you learned from your GCSE studies. At AS/A2 most questions are on human disruption to the cycle, especially the enhanced greenhouse effect.

The greenhouse effect is the natural warming of the lower atmosphere (troposphere) as a result of certain gases (the greenhouse gases) trapping or delaying the release of longwave radiation that has radiated from the ground surface.

Greenhouse gases include water vapour, NO_x, CH_4, tropospheric ozone and CFCs. Humans have increased the concentration of NO_x, CH_4, and tropospheric ozone and have invented CFCs

The main natural and man - made (anthropogenic) sources of these gases are summarised in Table 1.

Table 1 Natural and man-made sources of greenhouse gases

Pollutant	Source
NO_x	denitrifying bacteria, burning fossil fuels in vehicles
CH_4	increasing population of cattle/ ruminants, anaerobic decomposition in landfill sites, rice paddy fields
Tropospheric ozone	photolysis of NO_2 from vehicle exhausts
CFCs	in developing countries CFCs are still used as refrigerants, foam expanders and in aerosols

As the concentration of these gases increases in the troposphere, more longwave radiation is trapped and the temperature of the troposphere increases. This is causing:

- Melting of ice in the Arctic and Antarctic
- Thermal expansion of water
- Increased sea levels which will increase flooding, destruction of soils through salinisation, destruction of coastline and loss of habitats

Increased crop growth, due to raised temperatures, will occur in some areas as the rate of photosynthesis or the length of the growing season increases but growth rates will decrease in other areas because of water shortages.

As areas in the northern latitudes become warmer, species will migrate northwards. The effect of this is difficult to predict but there will be increased competition between species and animals may migrate out of protected areas such as National Parks.

Exam Hint *- The greenhouse effect is a simple topic but students make two common mistakes:*

1. *They state that warming occurs because longwave radiation is reflected from the earth's surface. This isn't the reason. It is radiated.*
2. *Students suggest that SO_2 is a greenhouse gas. It isn't.*

The Nitrogen Cycle

Year after year, the nitrogen cycle catches students out. The commonest problems are that students :

- Confuse nitrogen fixation, nitrification and denitrification
- Confuse the bacteria involved
- Struggle to see the connections between the cycle and related topics such as water pollution, plant adaptations and farming practices.

Before learning to draw the cycle you should make sure that you understand each of the processes.

Nitrogen fixation is the conversion of gaseous nitrogen into ammonia. Humans do this in the Haber process. The ammonia is often used to make nitrogen- containing fertilisers such as ammonium nitrate. Artificial fertilisers such as this are essential for intensive agriculture. Harvesting crops removes large amounts of nitrates and other nutrients. These must be replaced if fertility is to be maintained.

Bacteria also carry out nitrogen fixation:

- Azotobacter fixes nitrogen in aerobic soils
- Rhizobium fixes nitrogen in the roots of plants of the Papilionaceae such as peas, clover. Most exam questions are on Rhizobium, and you should learn the following outline.

Fixation by Rhizobium and Azotobacter

1. Rhizobium invades roots of plant.
2. The plant responds by forming nodules around the bacteria.
3. Rhizobium fixes nitrogen i.e. converts it into ammonia.
4. To do this the bacterium uses ATP (provides energy) and $NADPH_2$ (provides the hydrogen for reducing the nitrogen)
5. The plant converts ammonia into amino acids which are transported around the plant in the xylem
6. The relationship between the plant and the bacteria is an example of mutualism – two organisms living closely together, with each meeting some of the other's needs. Here, the plant provides the bacteria with a protected environment and with sugars. The bacteria provide the plant with a form of nitrogen that it can use to make proteins.
7. Azotobacter is a free living nitrogen fixing bacterium in the soil.

Common exam questions

1. Define nitrogen fixation
2. Why is the relationship between Rhizobium and the plant considered an example of mutualism?
3. What is the significance of the nodule that the plant forms around Rhizobium?

Question 3 is crucial. The enzyme that nitrogen fixing bacteria use is nitrogenase. Nitrogenase is inactivated by oxygen. The function of the nodule is to greatly restrict the amount of oxygen to which the bacteria are exposed. Note, that some oxygen is needed so that the bacteria can make the 16ATP required to fix one molecule of nitrogen – but the nodule stops any more than this entering. Other organisms use similar strategies to protect nitrogenase from oxygen eg heterocysts in Cyanobacteria.

Herbivores obtain nitrogen by eating plants. Following digestion, absorption and assimilation the nitrogen becomes incorporated in the proteins and nucleic acids of the animal.

Animals and plants die. Decomposers release extracellular enzymes that digest their proteins into amino acids and then deaminate the amino acids into ammonia.

Excretory products such as urea in urine are also broken down into ammonia. This is known as ammonification.

The ammonia that is released into the soil may diffuse into the atmosphere or dissolve in soil moisture to form ammonium ions and bind to clay particles. Ammonium ions bind tightly to the negative charges on clay particles in the soil and are therefore more difficult to absorb than nitrate ions.

The ammonium ions may also be transformed into nitrite and then nitrate ions in the process of nitrification:

$$NH_4^+ \xrightarrow[\text{Nitrosomonas}]{+\ O_2} NO_2^- \xrightarrow[\text{Nitrobacter}]{+\ O_2} NO_3^-$$

Nitrosomonas and Nitrobacter are therefore known as nitrifying bacteria. They are examples of chemosynthetic bacteria, obtaining their energy by oxidising the NH_4 and NO_2 ions respectively.

Another common exam question

Why may waterlogged soils be infertile?

1. Plant roots need oxygen if they are to actively absorb nutrients (the oxygen is needed to make the ATP for active uptake). In waterlogged soils water is taking the place of the oxygen containing air.

2. Nitrifying bacteria that make nitrate available to plant roots need oxygen, so if there's insufficient oxygen, nitrates will be in short supply and fertility reduced.

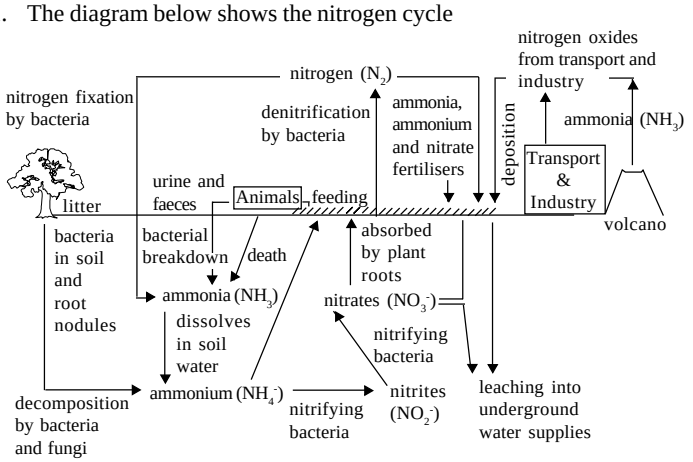
3. Downward movement of water will leach away the highly soluble nitrates

Finally, there has to be a mechanism to return gaseous nitrogen to the atmosphere. This is carried out by denitrifying bacteria such as Pseudomonas and Thiobacillus. These genera of bacteria convert nitrates into nitrogen. Denitrification occurs fastest in wet soils since the bacteria involved are anaerobic. Thus, this is the fourth reason that waterlogged soils may be infertile.

Carnivorous plants such as the greater sundew have adapted to boggy, nitrate-deficient soils by trapping and digesting insects which provide an alternative nitrogen source.

Practice Questions

1. The diagram below shows the nitrogen cycle



(a) Suggest how the following human activities have disrupted the natural nitrogen cycle.
(i) agriculture: 4
(ii) transport: 3

(b) Describe the process of nitrification: 3

Total 10

2. The table below describes some of the features of organisms which are able to carry out nitrogen fixation.

Organism	Feature
root nodules of clover (a legume)	contain haemoglobin
Cyanobacteria	contain heterocysts which are specialised cells where nitrogen fixation occurs, but photosynthesis does not
Azotobacter (a free-living soil bacterium)	maintains a very high rate of aerobic respiration in certain cells

(a) What is meant by the term nitrogen fixation? 2
(b) Suggest the significance of the features shown in the table. 2
(c) (i) It is possible that other species of plant may be genetically modified to give them nitrogen fixing ability. Outline the possible harmful effects of this. 3

(ii) Suggest why ploughing and drainage of arable fields may reduce denitrification. 2

Total 9

Answers

1. (a) (i) increased artificial fixation/conversion of N_2 to NH_3/Haber process/production of artificial nitrogenous fertilisers;
increased use of manure from intensive stock farming;
increased leaching of nitrates;
increased mineralisation/release of NO_2 / N_2O by ploughing/ burning; 4

(ii) increased use of fossil fuels;
increased release of nitrogen oxides into atmosphere;
increased acid rain/nitric/nitrous acid; 3

(b) conversion of ammonium/NH_4^+ into nitrate/ NO_2^- into nitrate (NO_3^-) ions;
credit correct genus e.g.
Nitrosomonas $NH_4^+ \rightarrow NO_2^-$;
Nitrobacter $NO_2^- \rightarrow NO_3^-$; 3

Total 10

2. (a) conversion of atmospheric/gaseous nitrogen to ammonia $N_2 \rightarrow NH_3$;
ammonia can be used by the plant/bacteria to synthesise amino acids/protein; 2

(b) all protect the enzyme/nitrogenase from oxygen/high oxygen concentrations;
oxygen is a competitive inhibitor of nitrogenase;
nitrogenase reduces the nitrogen molecule into ammonia; max 2

(c) (i) may give plant extra survival value/faster growth/reproductive rate;
outcompeting other plants in the environment;
which may not survive/become extinct;
fundamentally changing the community in a disadvantageous way/leading to a loss of insects/insect food plants/breaking food chains/loss of biodiversity; 3

(ii) dentrification occurs in anaerobic/waterlogged conditions;
ploughing/draining reduces this/aerates soil;
Thiobacillus/Pseudomanas denitrificans are anaerobic organisms; max 2

Total 9

Acknowledgements;
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ISSN 1351-5136