1.5 Energy Transfers in and between Organisms

AQA 7402 · Calculator allowed · about 185 minutes · Write-in edition

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 Photosynthesis begins with the light-dependent reactions, which take place on and across the thylakoid membranes of the chloroplast.

(a) State the two products of the light-dependent reactions that are required for the light-independent reactions (the Calvin cycle). **(2)**

(b) Describe how a proton (H^+) gradient is generated across the thylakoid membrane during non-cyclic photophosphorylation. **(3)**

(c) Explain how ATP synthase uses the proton gradient described in part (b) to produce ATP. **(3)**

(Total for Question 1 is 8 marks)

2 The nitrogen cycle involves several groups of soil bacteria that convert nitrogen between different chemical forms.

(a) Name the type of bacteria responsible for each of the following processes: (i) conversion of atmospheric nitrogen gas (N_2) into ammonium compounds; (ii) conversion of ammonium ions into nitrite ions; (iii) conversion of nitrate ions into atmospheric nitrogen gas. **(3)**

(b) Explain the mutualistic relationship between Rhizobium bacteria and leguminous plants (e.g. peas, clover) growing in root nodules. **(2)**

(c) Farmers can increase nitrate availability in soil either by growing leguminous crops as part of a crop rotation, or by applying inorganic nitrogen fertiliser. Evaluate the environmental impact of using inorganic nitrogen fertiliser instead of crop rotation with legumes. **(3)**

(Total for Question 2 is 8 marks)

3 Identify the correct answer for each of the following.

(a) Which molecule acts as the final electron acceptor in the electron transport chain during aerobic respiration? **(1)**

- ☐ A) NAD
- ☐ B) Oxygen
- ☐ C) FAD
- ☐ D) Pyruvate

(b) Which process converts nitrite ions (NO_2^-) into nitrate ions (NO_3^-)? **(1)**

- ☐ A) Nitrogen fixation
- ☐ B) Ammonification
- ☐ C) Nitrification
- ☐ D) Denitrification

(c) Which enzyme catalyses the fixation of carbon dioxide by combining it with RuBP in the light-independent reactions? **(1)**

- ☐ A) ATP synthase
- ☐ B) RuBisCO
- ☐ C) DNA polymerase
- ☐ D) Catalase

(d) Which statement best describes gross primary productivity (GPP)? **(1)**

- ☐ A) The total energy available to primary consumers after respiratory losses
- ☐ B) The total chemical energy store in producer biomass at a single point in time
- ☐ C) The total chemical energy fixed by photosynthesis per unit area per unit time
- ☐ D) The total energy transferred to secondary consumers

(e) Which term describes the loss of nitrogen from soil as nitrogen gas, occurring under anaerobic (waterlogged) soil conditions? **(1)**

- ☐ A) Nitrification
- ☐ B) Denitrification
- ☐ C) Ammonification
- ☐ D) Nitrogen fixation

(Total for Question 3 is 5 marks)

4 This question concerns respiratory energy yield and rates. A sample of actively respiring yeast is provided in a sealed respirometer chamber with glucose substrate. The chamber has internal volume 250 cm^3. Over 5.0 minutes the drop in internal oxygen partial pressure corresponds to 8.0×10^{-3} mol of O_2 consumed. Assume aerobic respiration of glucose is $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ and that each mole of O_2 consumed in oxidative phosphorylation leads to synthesis of 2.5 mol ATP (the P:O ratio for NADH-linked respiration).

(a) Calculate the mean rate of oxygen consumption in mol s^{-1} for the yeast sample over the 5.0 minute period. **(2)**

(b) Using the respiratory stoichiometry and P:O ratio given, calculate the total number of moles of ATP synthesised in the chamber over the 5.0 minute period. **(3)**

(c) Estimate the mean ATP synthesis rate in mol s^{-1} in this sample and the rate expressed in micromol s^{-1} (1 micromol = 1.0×10^{-6} mol). **(3)**

(d) State one experimental factor that could cause the measured O_2 consumption to underestimate true ATP synthesis rate in the cells, and briefly explain why. **(2)**

(Total for Question 4 is 10 marks)

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5 A student calculated an energy budget for a population of voles. The voles had a food energy intake (I) of 15000 kJ m^{-2} $year^{-1}$. Energy lost in faeces and urine (F+U) was 9000 kJ m^{-2} $year^{-1}$, and energy used in respiration (R) was 5850 kJ m^{-2} $year^{-1}$.

(a) Using the equation P = I - (F+U) - R, show that the net production (P) of the vole population is 150 kJ m^{-2} $year^{-1}$. **(2)**

(b) State what happens to the energy in the net production (P) that is not consumed by the next trophic level. **(1)**

(c) Explain, in terms of energy flow, why only a small percentage of the Sun's energy incident on a habitat is ultimately fixed by photosynthesis. **(3)**

(Total for Question 5 is 6 marks)

6 Required practical. A student used a respirometer to investigate the rate of oxygen consumption by blowfly larvae (maggots). The apparatus had two tubes connected to a manometer containing coloured fluid: one tube contained the maggots with soda lime, the other (the control tube) contained an equal volume of inert glass beads with soda lime. As the maggots respired, the coloured fluid in the manometer moved towards the tube containing the maggots.

(a) Explain the purpose of the soda lime in the apparatus. **(2)**

(b) Explain the purpose of the control tube containing inert glass beads. **(1)**

(c) The manometer capillary tube has an internal radius of 1.0 mm. During the experiment, the coloured fluid moved 30 mm along the tube in 5.0 minutes. Using volume = $\pi \times r^2 \times$ length, calculate the volume of oxygen consumed, in cm^3. Give your answer to 3 significant figures. **(2)**

(d) The mass of maggots used was 2.0 g. Using your answer to part (c), calculate the rate of oxygen consumption per gram of maggots, in $cm^3\ g^{-1}\ min^{-1}$. Give your answer to 2 significant figures. **(3)**

(e) Suggest one reason why the value calculated in part (d) might be an underestimate of the true rate of aerobic respiration of the maggots. **(2)**

(Total for Question 6 is 10 marks)

7 In a woodland ecosystem, the producers had a gross primary productivity (GPP) of 18500 kJ m^{-2} $year^{-1}$. The producers used 11200 kJ m^{-2} $year^{-1}$ in respiration (R).

(a) Define the term 'net primary productivity' (NPP). **(1)**

(b) Calculate the net primary productivity (NPP) of the producers. Show your working. **(2)**

(c) The primary consumers in the woodland had a net productivity of 730 kJ m^{-2} $year^{-1}$. Calculate the percentage of the producers' NPP (from part b) that is transferred to primary consumers. **(2)**

(d) Suggest one reason why not all of the energy in the producers' net primary productivity is transferred to primary consumers. **(1)**

(Total for Question 7 is 6 marks)

8 Photosynthetic efficiency and rates. A leaf disk experiment measures net photosynthetic O_2 production. At 400 micromol m^{-2} s^{-1} photon flux, a leaf area of 0.020 m^2 produces 1.80 x 10^{-4} mol O_2 in 10 minutes. Assume 8 photons are required to produce one O_2 in the light reactions (minimum quantum requirement).

(a) Calculate the total number of photons incident on the leaf area during the 10 minute period. **(3)**

(b) Using the quantum requirement given, calculate the theoretical maximum mol of O_2 that could be produced from the incident photons and compare with the observed 1.80 x 10^{-4} mol O_2. Hence calculate the light-use efficiency defined as (observed O_2 / theoretical max O_2) x 100%. Give the efficiency to 2 significant figures. **(4)**

(c) State one biological factor that could explain why observed O_2 production is much lower than theoretical maximum. **(1)**

(Total for Question 8 is 8 marks)

9 Uncertainty and significant figures in biomass transfer measurements. A student measures plant biomass energy as 6.50×10^3 kJ m^{-2} yr^{-1} with an absolute uncertainty of $\pm 1.5 \times 10^2$ kJ m^{-2} yr^{-1}. Using values from question 15, calculate the propagated uncertainty (absolute) in the amount of plant biomass energy ingested by herbivores (ingested = NPP x 0.18). Give your final ingested value with its absolute uncertainty and state the appropriate number of significant figures.

(a) Calculate the ingested value and its absolute uncertainty propagated from the NPP measurement. Use linear propagation for multiplication: absolute uncertainty in product = factor x absolute uncertainty in NPP. **(6)**

(b) Explain briefly why percentage uncertainty is a more useful comparison than absolute uncertainty when comparing the reliability of two biomass measurements of different magnitudes. **(3)**

(Total for Question 9 is 9 marks)

10 The table shows energy values for the trophic levels of a grassland food chain: grass (producers) -> grasshoppers (primary consumers) -> foxes (secondary consumers), recorded over one year. Producers: NPP = 9000 kJ m^{-2} $year^{-1}$. Grasshoppers: energy intake = 900 kJ m^{-2} $year^{-1}$; production (biomass produced) = 90 kJ m^{-2} $year^{-1}$. Foxes: energy intake = 9 kJ m^{-2} $year^{-1}$; production = 0.18 kJ m^{-2} $year^{-1}$.

(a) Calculate the percentage efficiency of energy transfer from the producers' NPP to the grasshoppers' energy intake. **(2)**

(b) Calculate the production efficiency of the grasshoppers (production as a percentage of energy intake). **(2)**

(c) Calculate the production efficiency of the foxes (production as a percentage of energy intake). Give your answer to an appropriate number of significant figures. **(2)**

(d) Foxes are mammals and maintain a constant, relatively high body temperature (endotherms), whereas grasshoppers are insects that do not regulate their body temperature (ectotherms). Use your answers to parts (b) and (c) to explain why the production efficiency of the foxes is lower than that of the grasshoppers. **(2)**

(Total for Question 10 is 8 marks)

11 A plant physiologist measured the net (apparent) rate of oxygen production by an aquatic plant at different light intensities, and separately measured the rate of oxygen consumption in the dark (respiration rate) as 2.0 arbitrary units per hour. At a light intensity of 8 units, the net rate of oxygen production was 6.0 units per hour.

(a) Calculate the true (gross) rate of photosynthesis at this light intensity. **(2)**

(b) Define the term 'light compensation point'. **(2)**

(c) Explain what would happen to the net production of biomass by the plant if light intensity were maintained below the compensation point for a prolonged period. **(2)**

(d) A commercial glasshouse grower raises the carbon dioxide concentration well above normal atmospheric levels while keeping light intensity and temperature constant. Explain why, above a certain CO_2 concentration, further increases in CO_2 produce no further increase in the rate of photosynthesis. **(2)**

(Total for Question 11 is 8 marks)

12 A farmer wants to increase the efficiency of energy transfer to a herd of beef cattle. He is considering two intensive farming methods: (1) keeping the cattle indoors in temperature-controlled barns with restricted space to move; (2) treating the cattle with growth-promoting hormones. Discuss how each method could increase the efficiency of energy transfer to the cattle, and evaluate the ethical and environmental issues raised by these farming practices.

(Total for Question 12 is 6 marks)

13 Explain why the efficiency of energy transfer between successive trophic levels in an ecosystem is generally low, and explain why food chains rarely contain more than about five trophic levels.

(Total for Question 13 is 6 marks)

14 Data interpretation: a researcher reports yearly energy budgets for two meadow management strategies A and B. Strategy A yields NPP = 5200 kJ m^{-2} yr^{-1} with herbivore consumption fraction 0.22 and assimilation efficiency 0.32. Strategy B yields NPP = 6000 kJ m^{-2} yr^{-1} with herbivore consumption fraction 0.15 and assimilation efficiency 0.38. Respiration fraction of assimilated energy is 45% for both strategies. Which strategy produces greater secondary production per m^2 yr^{-1}? Show calculations and give the difference between strategies in kJ m^{-2} yr^{-1}. Conclude which strategy is better if the goal is to maximise secondary production available to herbivores.

(a) Calculate secondary production for strategy A and strategy B, showing intermediate steps (ingested, assimilated, then secondary production). **(4)**

(b) Calculate the difference in secondary production and state which strategy is better for maximising herbivore secondary production. **(2)**

(Total for Question 14 is 6 marks)

15 Biomass and transfer efficiency in a simple food chain. A grassland plot produces 6.50×10^3 kJ m^{-2} yr^{-1} of net primary production (biomass energy). Herbivores grazing this plot consume 18% of the plant biomass. Of the plant biomass consumed, 30% is assimilated and the rest is egested. Of assimilated energy, 40% is used for respiration and the remainder is available for growth and reproduction (secondary production).

(a) Calculate the amount of plant biomass energy (in kJ m^{-2} yr^{-1}) that is ingested by herbivores. **(2)**

(b) Calculate the assimilated energy and the energy lost as egested material (kJ m^{-2} yr^{-1}). **(3)**

(c) Calculate the secondary production (growth and reproduction energy) available to the herbivore population after respiration losses. **(3)**

(Total for Question 15 is 8 marks)

16 Levels of response question. Evaluate how human activities can alter the efficiency of energy transfer through a terrestrial ecosystem. In your answer consider both direct effects on primary productivity and indirect effects on trophic transfer efficiency. Use examples where appropriate.

(Total for Question 16 is 6 marks)

17 Synoptic question linking ecology and cellular energetics. An agricultural scientist proposes planting a nitrogen-fixing crop in rotation with wheat to increase long-term wheat yields. Discuss quantitatively and qualitatively how adding nitrogen-fixing plants could change net primary productivity, the assimilation efficiency of herbivores grazing on the system, and the potential secondary production in a simple model where NPP increases by 20% and plant tissue nitrogen concentration rises so that assimilation efficiency of herbivores increases from 30% to 36%. Use the baseline values from question 15 (original NPP = 6500 kJ m^{-2} yr^{-1}, herbivore consumption fraction = 0.18, respiration fraction of assimilated energy unchanged at 40%).

(a) Calculate the new NPP, the new ingested energy by herbivores, the assimilated energy with increased assimilation efficiency, and the resulting secondary production after respiration. Show calculations and give final numeric values (kJ m^{-2} yr^{-1}). **(6)**

(b) Briefly evaluate two ecological trade-offs or unintended consequences of introducing nitrogen-fixing crops that the scientist should consider beyond the direct increases in NPP and secondary production. **(4)**

(Total for Question 17 is 10 marks)

Mark scheme · 1.5 Energy Transfers in and between Organisms

Question 1

(a) ATP **B1**

(a) reduced NADP (NADPH) **B1**

(a) Answer: ATP and reduced NADP

(b) photoactivation of chlorophyll at photosystem II releases (excited) electrons **B1**

(b) electrons pass along the electron transport chain, releasing energy that is used to actively pump H^+ into the thylakoid space (lumen) **B1**

(b) photolysis of water also releases H^+ (and electrons and O_2) directly into the thylakoid space, adding to the gradient **B1**

(b) Answer: Electron transport chain pumps H^+ into the thylakoid lumen; photolysis of water also releases H^+ into the lumen, both increasing H^+ concentration compared with the stroma.

(c) protons diffuse down their concentration (electrochemical) gradient through ATP synthase, from the thylakoid space into the stroma **B1**

(c) this process is called chemiosmosis **B1**

(c) energy released as protons flow through the enzyme is used to bond ADP and inorganic phosphate (Pi) together, forming ATP **B1**

(c) Answer: Chemiosmosis: H^+ diffuse through ATP synthase down their gradient, and the energy released drives ADP + Pi -> ATP.

Question 2

(a) (i) nitrogen-fixing bacteria (e.g. Rhizobium or Azotobacter) **B1**

(a) (ii) nitrifying bacteria (e.g. Nitrosomonas) **B1**

(a) (iii) denitrifying bacteria **B1**

(a) Answer: (i) Nitrogen-fixing bacteria; (ii) Nitrifying bacteria (Nitrosomonas); (iii) Denitrifying bacteria

(b) Rhizobium fixes atmospheric nitrogen into ammonium/nitrogen-containing compounds that the plant can absorb and use, e.g. to make amino acids **B1**

(b) in return, the plant supplies the bacteria with carbohydrates (organic compounds from photosynthesis) as a source of energy/carbon **B1**

(b) Answer: Rhizobium provides fixed nitrogen compounds to the plant; the plant provides carbohydrates to the bacteria.

(c) excess inorganic nitrate not taken up by crops can leach into waterways, causing eutrophication (algal bloom, death of aquatic plants, decomposer respiration depletes dissolved oxygen, death of aquatic animals) **B1**

(c) crop rotation with legumes is more sustainable as it does not rely on manufactured fertiliser, whose production (Haber process) is energy-intensive and produces greenhouse gases **B1**

(c) valid comparative judgement, e.g. inorganic fertiliser gives a faster/more controllable increase in nitrate but at a greater long-term environmental cost than legume rotation **B1**

(c) Answer: Inorganic fertiliser risks leaching/eutrophication and has a high energy/carbon cost of manufacture; legume rotation is more sustainable but slower acting.

Question 3

(a) B (oxygen) **B1**

(a) Answer: B) Oxygen

(b) C (nitrification) **B1**

(b) Answer: C) Nitrification

(c) B (RuBisCO) **B1**

(c) Answer: B) RuBisCO

(d) C **B1**

(d) Answer: C

(e) B (denitrification) **B1**

(e) Answer: B) Denitrification

Question 4

(a) method: divide moles consumed by total time in seconds, i.e. $8.0 \times 10^{-3} / (5.0 \times 60)$ **M1**

(a) 2.67×10^{-5} mol s^{-1} cao **A1**

(a) Answer: 2.67×10^{-5} mol s^{-1}

(b) method: ATP moles = (moles O_2 consumed) x (ATP produced per O_2) = $8.0 \times 10^{-3} \times 2.5$ **M1**

(b) evaluate product to 2 sf or 3 sf **M1**

(b) 2.00×10^{-2} mol ATP, cao **A1**

(b) Answer: 2.00×10^{-2} mol ATP

(c) divide moles ATP (2.00×10^{-2}) by time in seconds (300 s) **M1**

(c) correct numerical evaluation to give mol s^{-1} **M1**

(c) 6.67×10^{-5} mol s^{-1} and 66.7 micromol s^{-1}, cao **A1**

(c) Answer: 6.67×10^{-5} mol s^{-1}; 66.7 micromol s^{-1}

(d) any one correct factor such as some oxygen used for non-ATP producing processes (e.g. reactive oxygen species formation), or leakage of O_2 in apparatus, or cells performing anaerobic metabolism concurrently **B1**

(d) brief explanation linked to factor, e.g. leakage causes measured O_2 decrease to be smaller than true consumption or non-ATP uses mean less ATP per O_2 **B1**

(d) Answer: Leakage of O_2 from the chamber, so measured O_2 decrease is smaller than true cellular O_2 consumption.

Question 5

(a) 15000 - 9000 - 5850 (working shown) **M1**

(a) = 150 kJ m^{-2} $year^{-1}$ cso (answer given) **A1**

(a) Answer: 150 kJ m^{-2} $year^{-1}$ (given)

(b) it remains as dead organic matter and is broken down by decomposers/detritivores (returning carbon/nutrients to the abiotic environment, with further energy lost as heat via decomposer respiration) **B1**

(b) Answer: It is broken down by decomposers, returning nutrients to the environment.

(c) only certain wavelengths of light are absorbed by photosynthetic pigments (chlorophyll); other wavelengths (e.g. green light) are reflected or transmitted and not used **B1**

(c) much of the light reaching a habitat is not intercepted by chlorophyll/leaves at all (e.g. it reflects off non-photosynthetic surfaces, hits bare ground, or is absorbed by clouds/atmosphere before reaching plants) **B1**

(c) some absorbed light energy is lost as heat rather than being converted into chemical energy during the light-dependent reactions **B1**

(c) Answer: Wrong wavelengths are reflected/transmitted, much light misses chlorophyll entirely, and some absorbed energy is lost as heat rather than fixed.

Question 6

(a) soda lime absorbs the carbon dioxide released by the maggots during respiration **B1**

(a) so any change in gas volume/pressure detected is due only to the uptake of oxygen, allowing oxygen consumption to be measured **B1**

(a) Answer: Soda lime absorbs CO_2 so the fluid movement reflects O_2 uptake only.

(b) controls for (corrects for) fluid movement caused by changes in temperature or atmospheric pressure rather than by respiration, so the comparison is valid **B1**

(b) Answer: It corrects for fluid movement caused by temperature/pressure changes, not respiration.

(c) correct unit conversion: r = 1.0 mm = 0.1 cm, length = 30 mm = 3.0 cm **M1**

(c) volume = π x $(0.1)^2$ x 3.0 = 0.0942 cm^3 (awrt 0.094 cm^3) **A1**

(c) Answer: 0.0942 cm^3

(d) rate = volume / time = 0.0942 / 5.0 = 0.01884 cm^3 min^{-1} (ft from (c)) **M1**

(d) rate per gram = 0.01884 / 2.0 (ft from (c)) **M1**

(d) 0.0094 cm^3 g^{-1} min^{-1} (2 s.f.) awrt **A1**

(d) Answer: 0.0094 cm^3 g^{-1} min^{-1}

(e) small leaks at the joints/seals of the apparatus allow gas exchange with the atmosphere **B1**

(e) this reduces the pressure change detected, so less fluid movement occurs than would be expected from respiration alone, giving a lower calculated rate than the true rate **B1**

(e) Answer: Leaks in the apparatus reduce the recorded pressure change, so the calculated rate is lower than the true rate.

Question 7

(a) the rate at which energy (or biomass) is stored/made available to primary consumers, i.e. GPP minus respiratory losses (R): NPP = GPP - R **B1**

(a) Answer: NPP = GPP - R: the energy remaining after the producers' own respiratory losses.

(b) NPP = GPP - R = 18500 - 11200 **M1**

(b) 7300 kJ m^{-2} $year^{-1}$ cao (correct unit required) **A1**

(b) Answer: 7300 kJ m^{-2} $year^{-1}$

(c) (730 / 7300) x 100 (ft from (b)) **M1**

(c) 10 (%) cao **A1**

(c) Answer: 10%

(d) not all plant material is eaten (e.g. roots are inaccessible, or the plant is not found/eaten before it dies) and/or some ingested material is indigestible (e.g. cellulose/lignin) and egested as faeces rather than absorbed **B1**

(d) Answer: Some plant material is not eaten, or is egested undigested (e.g. cellulose), rather than absorbed by consumers.

Question 8

(a) method: photons per second per m2 x area x time = photon flux x area x time **M1**

(a) substitute: 400 micromol m^{-2} s^{-1} = 400 x 10^{-6} mol m^{-2} s^{-1}; time = 600 s **M1**

(a) 4.80 x 10^{-3} mol photons, cao **A1**

(a) Answer: 4.80 x 10^{-3} mol photons

(b) method: theoretical O_2 = mol photons / 8 **M1**

(b) calculate theoretical O_2 = 4.80 x 10^{-3} / 8 = 6.00 x 10^{-4} mol **M1**

(b) efficiency = (observed/theoretical) x 100 = (1.80 x 10^{-4} / 6.00 x 10^{-4}) x 100 **M1**

(b) 30% (to 2 sf), cao **A1**

(b) Answer: 30%

(c) possible factors such as photoprotection dissipating energy as heat, inefficiencies in electron transport, photorespiration, limited CO_2, or respiration concurrent with photosynthesis **B1**

(c) Answer: Photorespiration reduces net O_2 production.

Question 9

(a) calculate ingested: 6500 x 0.18 = 1170 kJ m^{-2} yr^{-1} **M1**

(a) method for absolute uncertainty: uncertainty_ingested = 0.18 x $uncertainty_{NPP}$ **M1**

(a) substitute uncertainty: 0.18 x 150 = 27 kJ m^{-2} yr^{-1} **M1**

(a) state ingested with uncertainty before rounding: 1170 ± 27 **M1**

(a) determine appropriate significant figures consistent with uncertainty (uncertainty to 2 s.f. or 1 s.f.) and round value accordingly **M1**

(a) 1170 ± 27 kJ m^{-2} yr^{-1} (round to 3 significant figures for value and 2 significant figures for uncertainty) cao **A1**

(a) Answer: 1170 ± 27 kJ m^{-2} yr^{-1}

(b) percentage uncertainty normalises uncertainty to the magnitude of the measurement **B1**

(b) therefore allows comparison of relative precision between values of different sizes **B1**

(b) brief example or statement linking to decision making or comparing data reliability gains the third mark **B1**

(b) Answer: Percentage uncertainty normalises the error to the measurement size so one can compare relative precision; for example 27/1170 is about 2.3% compared with a 150/6500 = 2.3% for the original measurement.

Question 10

(a) (900 / 9000) x 100 **M1**

(a) 10 (%) cao **A1**

(a) Answer: 10%

(b) (90 / 900) x 100 **M1**

(b) 10 (%) cao **A1**

(b) Answer: 10%

(c) (0.18 / 9) x 100 **M1**

(c) 2.0 (%) cao **A1**

(c) Answer: 2.0%

(d) foxes (endotherms) use a much greater proportion of their absorbed/assimilated energy in respiration to generate metabolic heat and maintain a constant body temperature, compared with grasshoppers (ectotherms), which do not need to do this **B1**

(d) this means less of the energy intake is available to be converted into new biomass (growth/production) in foxes, giving a lower production efficiency (2.0%) than in grasshoppers (10%) **B1**

(d) Answer: Foxes lose far more energy as metabolic heat (thermoregulation) than grasshoppers, leaving less available for growth, so their production efficiency is lower.

Question 11

(a) gross photosynthesis = net (apparent) photosynthesis + respiration = 6.0 + 2.0 **M1**

(a) 8.0 units per hour cao **A1**

(a) Answer: 8.0 units per hour

(b) the light intensity at which the rate of gross (true) photosynthesis equals the rate of respiration **B1**

(b) so there is no net exchange of gas (O_2 or CO_2) between the plant and its environment (net photosynthesis = 0) **B1**

(b) Answer: The light intensity at which gross photosynthesis equals respiration rate, so net gas exchange is zero.

(c) the rate of respiration would exceed the rate of (gross) photosynthesis **B1**

(c) so the plant would have a net loss of organic material/mass (using up stored carbohydrate reserves), and could eventually die if this continued **B1**

(c) Answer: Respiration would exceed photosynthesis, causing a net loss of biomass over time.

(d) carbon dioxide concentration is no longer the limiting factor once photosynthesis rate plateaus **B1**

(d) light intensity or temperature (whichever is now in shortest supply) has become the new limiting factor, so the rate cannot increase further until that factor is increased **B1**

(d) Answer: CO_2 stops being limiting; another factor (light intensity or temperature) becomes limiting instead.

Question 12

Level 3 A detailed, well-linked discussion explains how both methods increase energy-transfer efficiency and gives a balanced evaluation of ethical and environmental issues, using accurate scientific terminology throughout. **5-6**

Level 2 Explains how one or both methods increase efficiency, with some evaluation of ethical or environmental issues; mostly clear but links between ideas may be incomplete. **3-4**

Level 1 Makes basic, largely unlinked statements about efficiency or about ethical/environmental issues, with limited detail or scientific reasoning. **1-2**

Level 0 No relevant content, or the response does not address the question. **0**

Indicative content:

- Keeping cattle indoors in a temperature-controlled barn reduces energy lost as heat to the environment (less energy needed for thermoregulation), so a greater proportion of the energy from food is available for growth/production of biomass
- Restricting movement reduces the energy used in respiration for muscle contraction and other activity, again increasing the proportion of ingested energy that can be converted into biomass (meat)
- Growth-promoting hormones can increase the rate of protein synthesis and growth rate, increasing biomass produced per unit of food consumed (improved feed conversion efficiency)
- Selective breeding for fast growth rate or good feed conversion could also be mentioned as a further method to increase efficiency
- Ethical issue: restricting movement and housing cattle in small pens may compromise animal welfare by preventing natural behaviour, potentially causing stress, injury or disease
- Ethical/health issue: use of hormones is controversial and banned in some regions (e.g. the EU) due to concerns over animal welfare and possible effects on human health from residues in meat
- Environmental issue: intensive indoor housing concentrates large volumes of waste (slurry), which can pollute watercourses (eutrophication) if not managed carefully
- Environmental issue: heating/maintaining barns and producing concentrated feed requires additional energy input and resources, which may increase the overall carbon footprint of production despite improved biological efficiency
- A balanced conclusion should weigh the gain in energy-transfer efficiency (and associated commercial benefit) against the animal welfare and environmental costs of intensive methods

Question 13

Level 3 A detailed and coherent explanation is given of why energy transfer between trophic levels is inefficient, and of why the number of trophic levels is limited. Ideas are logically linked using accurate scientific terminology throughout. **5-6**

Level 2 An explanation is given covering several reasons for energy loss and/or the limitation on trophic levels, generally clearly expressed, with mostly accurate terminology but some links between ideas may be missing. **3-4**

Level 1 Basic, generalised statements about energy loss are made (e.g. 'energy is lost as heat'), with little detail and limited or no reference to why trophic levels are limited. **1-2**

Level 0 No relevant content, or the response does not address the question. **0**

Indicative content:

- Not all biomass/organisms at one trophic level are consumed by the next trophic level; some organisms die without being eaten and are broken down by decomposers, so their energy passes to decomposers rather than to the next trophic level
- Some ingested material is indigestible (e.g. bone, cellulose, lignin) and is egested as faeces without being absorbed, so this energy is not available for growth
- Energy that is absorbed may be lost in excretory products (e.g. urea in urine) rather than being incorporated into biomass
- A large proportion of absorbed energy is used in respiration to generate ATP for movement, active transport and (in mammals and birds) maintaining a constant body temperature
- Energy used in respiration is ultimately released as heat to the surroundings and is not available to the next trophic level (in line with the second law of thermodynamics)
- As a result of these losses, typically only around 10% of the energy available at one trophic level is transferred to and incorporated into the biomass of the next
- Because energy availability falls sharply (geometrically) at each successive trophic level, after four or five transfers there is too little energy/biomass remaining to support a further viable population of consumers
- Top predators would need an impractically large feeding area/population of prey to obtain sufficient energy, which limits the number of trophic levels that can be sustained

Question 14

(a) calculate ingested A = 5200 x 0.22 = 1144 **M1**

(a) calculate assimilated A = 1144 x 0.32 = 366.08 **M1**

(a) calculate secondary production A = 366.08 x (1 - 0.45) = 201.34 **M1**

(a) repeat for B with correct numbers: ingested B = 6000 x 0.15 = 900; assimilated B = 900 x 0.38 = 342; secondary production B = 342 x 0.55 = 188.1 **M1**

(a) Answer: Strategy A secondary production = 201.3 kJ m^{-2} yr^{-1}; Strategy B secondary production = 188.1 kJ m^{-2} yr^{-1}

(b) compute difference = 201.34 - 188.1 = 13.24 **M1**

(b) Strategy A is better by 13.2 kJ m^{-2} yr^{-1}, cao **A1**

(b) Answer: Strategy A is better by 13.2 kJ m^{-2} yr^{-1}.

Question 15

(a) method: ingested = NPP x fraction consumed = 6.50 x 10^3 x 0.18 **M1**

(a) 1170 kJ m^{-2} yr^{-1}, cao **A1**

(a) Answer: 1170 kJ m^{-2} yr^{-1}

(b) assimilated = ingested x assimilation fraction = 1170 x 0.30 **M1**

(b) egested = ingested - assimilated **M1**

(b) assimilated = 351 kJ m^{-2} yr^{-1}; egested = 819 kJ m^{-2} yr^{-1}, cao **A1**

(b) Answer: Assimilated = 351 kJ m^{-2} yr^{-1}; Egested = 819 kJ m^{-2} yr^{-1}

(c) method: secondary production = assimilated x (1 - respiration fraction) = 351 x 0.60 **M1**

(c) numerical evaluation **M1**

(c) 210.6 kJ m^{-2} yr^{-1} (accept 211 kJ m^{-2} yr^{-1} to 3 sf), cao **A1**

(c) Answer: 210.6 kJ m^{-2} yr^{-1}

Question 16

Level 3 Detailed, balanced evaluation. Points include clear explanation of mechanisms by which human activities alter net primary productivity and trophic transfer efficiency, supported by relevant examples, and considered judgement about overall impact and magnitude. Quality of written communication is good. **5-6**

Level 2 Some evaluation with explanation of at least one mechanism and an example. Connections between primary productivity and transfer efficiency made but limited in breadth or depth. **3-4**

Level 1 Simple statements or descriptions with limited linkage, little or no evaluation, or unsupported assertions. **0-2**

Indicative content:

- Direct effects on primary productivity: nutrient enrichment from fertiliser increases primary productivity but may cause algal blooms, eutrophication and reduced light penetration; habitat destruction and deforestation reduce plant biomass and NPP.
- Indirect effects on trophic transfer: selective removal of predators or herbivores changes community structure and trophic efficiencies; intensive agriculture often increases harvestable secondary production per unit area but reduces energy passed to higher trophic levels by removing biomass (harvesting) and reducing biodiversity.
- Mechanistic links: increased NPP may raise energy available to herbivores but higher respiration losses from stressed plants or higher plant tissue C:N may lower assimilation efficiency; pesticides reduce assimilation and increase egestion due to digestive disruption.
- Examples: conversion of rainforest to pasture decreases total NPP and lowers transfer efficiency to top predators; well-managed agroecosystems can increase short-term secondary production but usually reduce ecosystem transfer efficiency and resilience.
- Balanced judgement: human activities can both increase and decrease efficiency; overall often reduce long-term ecosystem transfer efficiency and biodiversity, with short-term gains in yield.

Question 17

(a) calculate new NPP = 6500 x 1.20 = 7800 kJ m^{-2} yr^{-1} **M1**

(a) calculate ingested = 7800 x 0.18 **M1**

(a) calculate assimilated using new assimilation 0.36 **M1**

(a) calculate secondary production = assimilated x (1 - respiration fraction 0.40) **M1**

(a) correct numerical evaluation of ingested and assimilated and secondary production **M1**

(a) answers: new NPP 7800; ingested 1404; assimilated 505.44; secondary production 303.26 kJ m^{-2} yr^{-1} (awrt) **A1**

(a) Answer: New NPP = 7800 kJ m^{-2} yr^{-1}; Ingested = 1404 kJ m^{-2} yr^{-1}; Assimilated = 505.4 kJ m^{-2} yr^{-1}; Secondary production = 303.3 kJ m^{-2} yr^{-1}

(b) one trade-off such as increased risk of nitrate leaching and water pollution if nitrogen enters soil beyond plant uptake **B1**

(b) explain consequence for ecosystem services or biodiversity **B1**

(b) second trade-off such as changes in plant community composition favouring legumes over native species, altering food web and reducing long-term resilience **B1**

(b) brief explanation of how this affects long-term productivity or trophic transfer efficiency **B1**

(b) Answer: Trade-offs include nitrate leaching causing eutrophication of waterways and potential loss of biodiversity from favouring legumes, which can alter food-web structure and reduce resilience.