BSc Degree Examinations 2018-9

Department: BIOLOGY

Title of Exam: Plant-soil interactions

Time Allowed: 2 hours

Marking Scheme:
Total marks available for this paper: 100
Section A: Short Answer / Problem / Experimental Design questions (50 marks)
Section B: Essay question (marked out of 100, weighted 50 marks)

Instructions:
Section A: Answer all questions in the spaces provided on the examination paper
Section B: Answer either question A or B. Write your answer on the separate paper provided and attach it to the back of the question paper using the cable tie provided.

Materials Supplied: CALCULATOR
SECTION A: Short Answer / Problem / Experimental Design questions

Answer all questions in the spaces provided

Mark total for this section: 50

Question 1

a). State the dominant type of mycorrhizal association in each of the following biomes. No abbreviations please. (3 marks)

i) Arctic tundra  Ericoid

ii) Tropical savannah grassland  Arbuscular mycorrhiza

iii) Temperate forest  Ectomycorrhiza

b) The addition of arbuscular mycorrhiza fungi is often reported to increase host plant phosphorus contents under controlled conditions in laboratory or greenhouse studies but it is often more difficult to reproduce this beneficial effect under field conditions. Explain why this is the case. (5 marks)

NB: Explanation must be given to obtain full marks

P may not be limiting in the field. (1 mark)

Indigenous species of AMF present (1 mark) which may be less able to acquire P but more likely to colonise the roots (1 mark).

The external mycelium which explores an increased volume of soil for P acquisition (1 mark) may be grazed (1 mark) e.g. by soil animals and so the effectiveness of the AMF reduced.

Qu1 Relates to LO5 Be able to describe through the use of examples, the various types of mycorrhiza associations that can occur and be able to evaluate the ecological relevance of these different types of associations.
Question 2

You wish to measure how much recently fixed carbon is released by roots into the rhizosphere soil in the laboratory. Describe and explain how you would achieve this experimentally. You may assume that the experiment has sufficient replication.

(10 marks)

As recently fixed carbon is to be followed a pulse-chase experimental approach would be most appropriate.

Requires the shoot and root to be separated so specialised microcosm unit(s) with a separate shoot and root/soil chamber (1 mark) are required. Labelled CO\textsubscript{2} (either as \textsuperscript{13}CO\textsubscript{2} or \textsuperscript{14}CO\textsubscript{2}) (1 mark) is injected as a single, discrete ‘pulse’ (1 mark) into the shoot chamber. Additional credit for identifying \textsuperscript{14}CO\textsubscript{2} would be more appropriate for this study as it is more sensitive to detect (1 mark) - question states study is being conducted under laboratory ‘controlled’ conditions so no issues of using \textsuperscript{14}C in the field. Shoots allowed to assimilate the labelled CO\textsubscript{2} for c. 2 hours (a few hours acceptable) (i.e. 'pulse'-period) (1 mark). Followed by a ‘chase’ period. The chase period has to be carefully considered given the question asks how much 'recently fixed C' is released. So a relatively short chase period (a few hours; c. 3 hr ideal) is required (1 mark) as this will result in preferential partitioning of \textsuperscript{14}C to simple/low molecular weight compounds (1 mark). Longer chase periods would result in the label being present increasingly within less labile pools so would not be appropriate for the question asked.

At the end of the chase-period, the roots have to be removed, vigorously shaken (1 mark) and any soil still remaining to the roots deemed to be rhizosphere soil (i.e. the ‘operational’ definition of rhizosphere soil required) (1 mark). This soil is then removed from the roots and the amount of \textsuperscript{14}C determined by scintillation counting (or \textsuperscript{13}C determined via a mass spectrometer) (1 mark).

Appropriate credit given for other considerations in the experimental design i.e. using alkaline traps to capture respired labelled C but has to be properly integrated/relevant to the question and the main relevant points are listed in the model answer above.

LO3 Be able to critique the key interactions in the rhizosphere and the resulting impact upon both plant and microbial/soil animal communities.
Question 3

a) Briefly define what happens at the critical substrate C:N ratio. (2 marks)

At the critical substrate C:N ratio neither net N mineralisation nor immobilisation occurs (2 marks).

b) Calculate the critical substrate C:N ratio for an individual micro-organism with a C:N ratio of 8:1 decomposing a substrate containing 100 units of carbon (C) of which 40 units of C are respired. Show all calculations. (4 marks)

First the N requirement of the micro-organism needs to be calculated

100C - 40C respired = 60C (1 mark)

C:N ratio of micro-organism = 8:1

so N requirement = 60/8 = 7.5 (1 mark - if all calculations not shown as requested and only ‘7.5’ given then only 1 mark will be awarded for the N requirement part)

Critical Substrate C:N ratio of micro-organism

100C / 7.5 = 13.3 (or 100C divided by N requirement value calculated by student above). (1 mark)

Therefore, critical substrate C:N ratio is 13.3:1 (1 mark for reporting correctly as a ratio)

Qu Relates to LO6 Be able to describe the N cycle through being able to summarise the main N transformation reactions, how these transformations can be measured and their environmental consequences.
Question 4

Use the graph below to explain the impact of the various agricultural treatments and practises on wheat yields. (13 marks)

[No marks for stating control gives the lowest yield]

Adding more fertiliser N increased yields to the continuously grown wheat (1 mark) suggesting this system is N limited (1 mark). However, less fertiliser N can be added and yields still increase when FYM is also added (1 mark). The FYM adds organic matter back to the soil (1 mark) and thus improves soil health through improved water retention, soil structure etc (1 mark).

Introduction of ‘fallow’ increased yields in all cases (1 mark). The fallow period would help control for weeds (1 mark), as would application of weedkiller, and so reduce competition for resources (1 mark). In addition removal of weeds (introduction of weedkiller) and the fungicide introduction could also help control for soil bourne pathogen build up (1 mark).

Rotation of crops increases yields compared to continuously grown wheat (even when same level of fertiliser is added i.e. P & K + 144 kg N) (1 mark) as this also helps reduce soil pathogen build-up (1 mark).

Modern cultivars show increase yield over traditional cultivars (1 mark) because modern cultivars are more responsive to fertiliser additions (i.e. ‘green revolution’) (1 mark).

LO 7 Be able to critique the potential limits to achieving sustainable agricultural
systems through drawing upon evidence from agricultural advances and practises from the past to the present day.

Question 5

a) Briefly explain the significance of the ‘depletion zone’ that develops around an actively absorbing root. (2 marks)

It is the volume (accept ‘area’) of soil that effectively can be exploited by the root (1 mark) for a particular nutrient ion (or depletion zone size varies depending on the nutrient ion acceptable) (1 mark)

b) A soil has a diffusion coefficient for nitrate of $10^{-8}$ m$^2$ s$^{-1}$. Calculate the depletion zone around an actively absorbing root after $10^6$ s for this ion. Please show all calculations. (2 marks)

Nitrate:

$$2 \sqrt{D.t} = 2 \sqrt{(10^{-8} \times 10^6)} = 2 \sqrt{(10^2)} = 2 \times 10^{-1} \text{(1 mark)}$$

= 0.2 m or 200 mm (1 mark)

(c) Interpret what effect an increase in root length density of an individual plant would have on root uptake rates of nitrate and phosphate and why. (4 marks)

Uptake rates of both would decline (1 mark) but this decrease would be greater for nitrate than phosphate (1 mark) as depletion zones for nitrate are larger (1 mark) and more likely to overlap (1 mark) as root length density increases (thus there would be increased competition among roots of the same plant).

Qu relates to LO1 Be able to describe and calculate the main ways in which ions move in the soil environments and be able to critically evaluate the subsequent consequences for plant nutrient capture.

Question 6

Explain what would happen to bacterial and protozoa populations and nitrogen availability in a patch of decomposing organic material with low C:N ratio. (5 marks)

Bacterial numbers would increase rapidly to exploit the available substrate (1 mark). The expansion of the bacterial population attracts protozoa that feed on the bacteria (1 mark) so bacterial populations decline while protozoa populations increase before declining again once bacterial numbers are reduced (1 mark here only). Bacterial prey contain excess N for protozoan requirements (1 mark) so the N is excreted as
ammonia (often converted rapidly to NH$_4^+$) so N levels locally will increase (1 mark).

LO3 Be able to critique the key interactions in the rhizosphere and the resulting impact upon both plant and microbial/soil animal communities.

SECTION B: Essay question

Answer one question on the separate paper provided

Remember to write your candidate number at the top of the page and indicate whether you have answered question A or B

Mark total for this section: 50

EITHER

A) In soil, the distribution of nutrients is both spatially and temporally heterogeneous. Discuss how plant roots respond to such heterogeneity in resource supply, explaining which root traits may be important and why.

LO2: Be able to describe the main mechanisms by which roots interact with their environment and be able to interpret the relative importance of these interactions. Also

LO1: Be able to describe and calculate the main ways in which ions move in the soil environments and be able to critically evaluate the subsequent consequences for plant nutrient capture.

There are several ways this essay could be approached.
Physiological and morphological plasticity should be discussed for the ways in which roots respond to temporal and spatial nutrient heterogeneity with physiological changes (i.e. altered uptake rates) generally considered more important for temporal heterogeneity and morphological changes for spatial heterogeneity (providing the duration of the nutrient zone is long enough). Of the examples covered in the second lecture the work by Jackson et al 1990 illustrates that physiological changes can be both rapid and large - while the work by Drew in the 1970’s and Campbell et al. 1991 were given as detailed examples of morphological changes. Campbell et al showed that dominant plants responded to heterogeneity by scale (overall production) and competitively inferior plants by precision (being more precise where new root biomass is placed), with the caveat that this scale or precision response among ‘competitive’ groups has not received wide
support in different ecosystems.

Information on what root traits are important could be discussed from L2 and the ideotype for P capture i.e. including shallow basal roots (most of the P is in the upper layers), smaller diameter roots, greater specific root length (SRL), longer/denser root hairs, AM associations versus N capture (‘steep, cheap and deep’ traits i.e. steep growth angle of crown roots, deep placement in soil and cheap architectural and anatomically) discussed while appreciating roots are trying to acquire multiple nutrients so a root system designed to maximise P acquisition may be little benefit for N acquisition.

An impressive answer would effectively synthesize information from L1 (Soils and Ion Movement) on depletion zones due to nitrate v phosphate capture and L2 (‘roots’) to discuss, for example that as root length density increases there is more potential for depletion zones to overlap in the case of mobile ions such as nitrate as opposed to phosphate. Hence there would be increased competition between the roots of the same plant for the resources which would not be ideal. However even increased root length can benefit a plant in terms of N capture - when grown under the conditions of competition (as occurs in the field). Also how physiological changes in roots generally benefit uptake of ions with high mobility. In contrast, ions with lower mobility such as phosphate will only be enhanced if the nutrient zone or patch was very high. Information from L3 & 4 (‘Rhizosphere interactions) could also be included in the answer but must be discussed in a relevant way e.g. the increasing awareness that aerenchyma formation (discussed in relation to waterlogging conditions in L3) may also help reduce the cost of nutrient foraging by lowering maintenance costs of the root.

OR

B) Compare and contrast the impact of symbiotic and non-symbiotic nitrogen fixation in terrestrial ecosystems, and discuss their potential use in sustainable agricultural systems.

LO4: Be able to describe through the use of examples, the various types of N-fixation associations that can occur and be able to critique the ecological relevance of these associations.

Firstly, the organisms and types of association involved in N-fixation should be outlined i.e. can be carried out by a large range and number of prokaryotes which can be free-living, associative (loosely associated with roots) or symbiotic (close relationship and includes leaf symbiosis, Actinorhizal, Rhizobium and Coralloid roots). The first two categories are non-symbiotic the latter symbiotic. Some examples of each type should be given (as given in the lecture material). The N-fixation process should be outlined (e.g. conversion
of N\(_2\) to NH\(_3\), energetically expensive (16 ATP), involves nitrogenase enzyme complex).

Examples of the importance of symbiotic v's non-symbiotic N-fixation in different situations/ecosystems should then be outlined. Some examples include:
Rate of N gain in the Rothamsted ‘wilderness experiments’ over a c. 120 yr period likely due to non-symbiotic N-fixers (as few symbiotic associations at these field sites) but varied between the two sites as the free-living/associative N fixers sensitive to environmental factors.

Biological crusts (mixed community of cyanobacteria, microfungi, mosses and lichens) can add c. 1 kg ha\(^{-1}\) yr\(^{-1}\) N in arid/desert systems which although not a high figure is the main N input in such systems. The crusts are very sensitive to environmental change and may take decades to centuries to recover if disturbed.

**Symbiotic N fixation:** Can help shift the competitive balance between plants as shown by the Park Grass experimental plots where legumes compete better than grasses for phosphate when fertiliser with no additional N is applied.

Coils of Nostoc in feather moss (*Pleurozium schreberi*) leaves can fix 1.5 - 2 kg N ha\(^{-1}\) yr\(^{-1}\) in N limited Boreal forests representing a significant N input in these N limited systems. Moreover, following fire events an increase in N bioavailability in early successional forests down-regulate N-fixation, suggesting tight controls upon N cycling in these forest ecosystems.

Invasions of plants that can form N-fixing symbiosis can, however, be **harmful to native plant communities** on low N sites as shown by the invasion of the actinorhizal N-fixation shrub *Myrica faya* in Hawaii where soil N levels have greatly increased leading to the potential of further plant invasions and the demise of the native N-limited forest vegetation.

**Sustainable agricultural systems:** Finally, the essay should outline their potential in aiding ‘sustainable’ agricultural systems. Attempts to use associative N-fixers to enhance N supply in agricultural systems in 1970’s proved largely unsuccessful as associative N-fixers would obtain C supply from rhizodeposition (link to L3 in module) but calculations based on % population size of N-fixers, C translocated to this population via rhizodeposition and efficiency of of root released C conversion to N-fixation demonstrated that the N fixed would be insufficient to meet crop demand (even given different
calculations vary in the efficiency of C conversion values) and would only result in c. 15-23 kg N ha\(^{-1}\) yr\(^{-1}\) compared with the 100-300 kg N ha\(^{-1}\) yr\(^{-1}\) needed by a wheat crop to produce yields of 5-9 t ha\(^{-1}\). However, this N input can be important in natural ecosystems even if insufficient in agricultural ones. Although 'C efficiency' to N-fixation is greater for symbiotic than associative fixation (c. 6 g C g\(^{-1}\) N fixed) meaning less C is required to fix the same amount of N, but this can still represent a considerable C cost for the plant (example clover plants totally dependent upon Rhizobium for their N supply allocated 25% of their total fixed photosynthate to the microsymbiont).

A very good answer would explore other possibilities not covered in the lecture such as the potential for trying to incorporate N-fixing genes into crops in the future but also highlight issues regarding C costs.