Enhancing the use of near infrared spectroscopy in environmental research and monitoring

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Introduction

The sustainability of the natural environment and of agriculture depends on ecosystems that are resilient, adaptive and productive. These can better support people and conserve biological diversity. The boundaries between "environment" and "agriculture" are fuzzy and much research on food production can rightly claim to be "environmental" including soils, forages, and domestic animals. Resilient ecological systems rely on biochemical diversity. Biochemical diversity is found both within and between species of plants and animals. If we are to take advantage of this biochemical diversity to maintain productive ecosystems in the face of change, we need to be able to measure it rapidly, and Near Infrared (NIR) Reflectance Spectroscopy is the ideal tool.

NIR spectroscopy has long been used to monitor the environment, and also as an environmental research tool. The characteristics of NIR spectroscopy match well with environmental research. Nevertheless, even though environmental applications of NIR have featured at recent NIR congresses, there is a sense that the number and types of studies has not expanded as much as in the agricultural and pharmaceutical industries. This may be because of the nature of the technology and other factors associated with the types of questions that are asked in environmental science.

In order to encourage greater use of NIR in environmental applications there are four issues to consider. Previous reviews of this topic have identified additional issues.[1]

Embrace complexity of environmental processes

The major application of NIR in environmental research is the measurement of single compositional traits of plants, water or soils. Often these measurements are a proxy for more complex processes. For example, soil N or P is often used as an index of soil fertility, and foliar N is used as an indicator of plant quality for herbivores. Although NIR is invaluable in making such measurements rapidly and cheaply, it has great power to model such traits directly.[2]

Oftentimes the link between the attribute being measured and the functional outcome (e.g. the ability of the soil to support plant growth, the ability of the plant to support maintenance and reproduction of herbivores) is poorly understood. NIR spectroscopy is capable of predicting more complex traits such as plant growth or animal performance directly without the need for an intermediate chemical proxy.

For example, in studies of koalas, NIR models explained much more of the variation in food intake than did complex chemical models.[3] An even more powerful application is the prediction of food intake and diet quality from samples of faeces in a range of herbivore.[4] Other excellent examples where complex traits have been estimated by NIR include in litter decomposition[5] and water chemistry.[6]

Enhancing scale

Environmental processes occur at many different scales. For example, the factors that affect whether animals choose one plant over another might be very different from the factors that influence those animals to choose a particular vegetation type as their core habitat. Most NIR studies in environmental science are made at small to moderate scales. Of course, this may be entirely appropriate to the questions being posed but increasingly decision makers are requesting data at larger scales.

To gather such information, we need spectrometers that operate from an airborne or near-earth orbital platform. There has been little interaction between researchers in remote sensing and NIR, but the growth of hyperspectral imaging in both communities means that there is opportunity for greater interaction in data processing and analysis. Several studies have used a standard NIR calibration approach to spectra collected from aircraft flying between 2 km and 20 km above ground.

There are many complex issues to be addressed in translating spectral data from airborne instruments into interpretable conclusions. These include atmospheric corrections but the most challenging is in identifying pixels that represent the feature of interest.[7] A pixel from a single tree could contain reflectance from leaf, bark, bare ground and shadow! Although many techniques have been developed to address this issue, it is often not possible to identify "pure" pixels of the material of interest. A second significant difficulty in transferring a NIR laboratory-based calibration approach is in collecting sufficient samples to represent the spectral diversity of the materials being studied. Thirdly, the cost of acquiring data via airborne spectrometers is still high; particularly so if regular flights are needed to monitor change. However, new instruments that can be mounted on small, unmanned planes may soon be available.

Despite these challenges, enhancing the scale of measurements by marrying techniques from remote sensing and traditional NIR approaches is an area of great promise for environmental research. I predict that the boundaries between remote sensing and the NIR communities will continue to break down to facilitate large-scale environmental monitoring.

Increase portability

Portable NIR would seem to be an ideal tool for environmental applications. However, applications using benchtop instruments dominate both environmental and agricultural systems. The reasons are a complex mixture of performance, costs and tradition. Relatively few users invest only in portable instruments and most often "graduate" to portable spectrometers after gaining experience with benchtop instruments. Instrument cost is major limitation but new technologies may reduce this. However, costs, stability and transfer of calibrations remain significant. That aside, there are a large number of excellent applications using portable instruments that do demonstrate that there is no intrinsic barrier to developing calibrations for many diverse questions.[8–11]

Integration with decision support systems

The final way to enhance the use of NIR in environmental research is to identify at an early stage, how the data are to be used. For example, a very powerful application of NIR is the prediction of the composition of the diet of cattle from faeces that have been collected by farmers on rangelands.[12] NIR calibration models have been developed to predict traits such as the protein content of the diet consumed in the previous 1-2 d, its digestibility, and even the amount of pasture eaten. To be useful, these data must be translated into recommendations and management action quickly, and not several months later. The success of NIR-based approaches to the management of grazing animal nutrition in the USA and Australia owes as much to the close integration of the data with management systems as it does to the development of robust calibrations.

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