Near infrared spectroscopy for sustainable agricultural development and protection from food deficiency

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Introduction

The population of the world is now at 6.84 billion people and increasing at about 80 million per year. Therefore, there is an increasing dependence on a productive, stable and sustainable agricultural sector. Agriculture is responsible for the survival, the health and the quality of life of all people. The number of people who are starving or under-nourished clearly indicates that better management of the agricultural sector is required urgently.

Threats to the sustainable production of healthy food crops and fibres include changes which reduce the affordability or the effectiveness of light, temperature, soil properties, water supplies, energy, fertilizers, adapted plant genotypes, and pest and disease management. Each of these must be measured so that data are available for making immediate decisions. They must also be monitored so that long-term changes are detected and used to make appropriate management decisions. The challenge for NIR spectroscopists is to provide more reliable analytical data. The challenge for managers in the agricultural sector is to utilize NIR-based technology to achieve more per unit of land, per unit of water and per unit of fuel consumed.

Of the annual global production from crops in excess of 4 billion metric tonnes (t) of seeds, grains and fleshy fruits containing seeds, dry cereal grains plus the dry legume (pulse) seeds constitute almost 77% of the production.[1] FAO data assembled by Lott *et al.*[2] indicate that over the years 1995–2003 the four largest cereal crops were maize or corn (*Zea mays*), rice (*Oryza sativa*), wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*) with tonnage of about 595, 582, 580 and 142 million $t\,yr^{-1}$, respectively. Total cereals include the four listed above as well as rye, oats, sorghum, millets and others. For the dry legume seeds soybean (*Glycine max*) is the legume seed produced in greatest tonnage at 158 million $t\,yr^{-1}$. The total legumes include dry seeds of soybeans, beans, broad beans, peas, lentils, chickpeas, groundnuts, and others. Total dry cereal plus legume grain/seed production over a 9 year span was a mean of 2.3 billion t annually.

Increases in cereal production per ha may or may not be keeping pace with increases in the world population (Figure 1) but the demand for cereals and coarse grains increases with increases

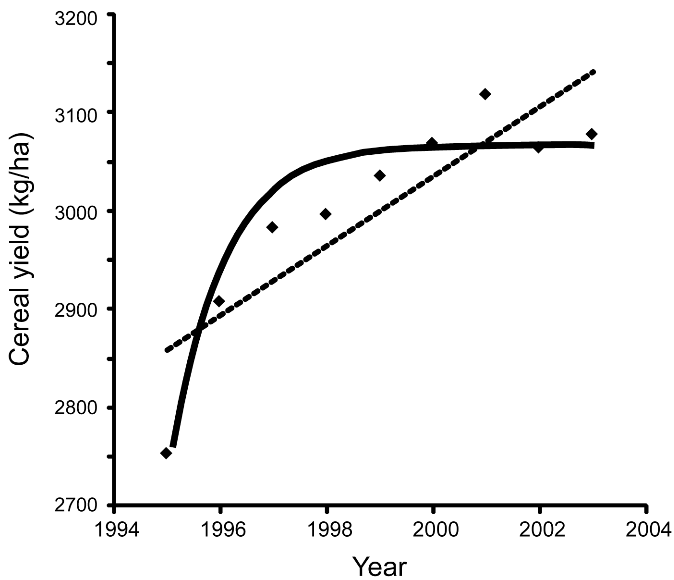

Figure 1. Trend in global cereal yields over nine years. The linear trend line (broken line) indicates an increase of 1.2% per annum. However, fitting the best simple curvilinear function suggests an arrested growth of cereal yields in the last four years of data (continuous line: $r^2 = 0.91$, $p = 0.00006$; equation: $Y = a + be^{-x}$; $a = 3056.6$, $b = 8.4$. Reprinted with permission of Inderscience from Lott *et al.*[2]

in population. In 2002 the FAO[3] suggested that "In future 80% of increased crop production will have to come from intensification: higher yields, increased multiple cropping and shorter fallow periods". Significant amounts of agricultural products are being diverted away from food production to energy-produce (fuels) to replace fossil-oil products. The net effect has been a reduction in available food for humans and large increases in the prices of some basic food staples.

NIR and the ability of the agricultural sector to provide foods and fibres

Major areas of once productive land have become less productive or non-productive due to several forms of degradation including desertification, over grazing, water-logging, erosion, salinity and sodicity, acidity, nutrient exhaustion, weed (including shrubs) infestation, and structural decline and urbanisation. "Sodicity" and salinity differ in that salinity in soils refers to the degree to which the soils are influenced by salt (NaCl) content, whereas the sodicity of a soil refers to the degree to which the soil is affected by the sodium ion content. Sodium ions affect the characteristics of clay colloids. The effects of sodicity include reduction of the air and water-holding capacity of soils, and increase in erosion potential. NIR technology can identify and be used to manage the threats to a productive agricultural sector. The simple nutrient difference vegetation index (NDVI; the ratio $(R_{770nm} - R_{660nm} / (R_{770nm} + R_{660nm})$ where R = reflectance) has been widely used to assess variation across landscapes; in many cases the variation is due to variation in available plant dry matter. The detection of salinity in soils,[4] and presumably any other soil property, using satellite, or airborne visible-NIR sensors, is directly and indirectly influenced by soil surface moisture, mineralogy, colour and surface roughness and adapted plant species. NIR spectroscopy can be used to map soil variability *in situ*[5] or, with reasonable accuracy, analyse soil samples in the laboratory.[6] Each approach has limitations and advantages.

NIR analyses should be incorporated into a) plant breeding programs to screen for water-use efficiency, resistance to diseases and pests (see Purcell, these proceedings), and b) into crop management to detect nutrient deficiencies weeds and pests. Studies in rice fields in Australia[7] revealed that NDVI images with a resolution on the ground of 1 m × 1 m were able to estimate dry matter variation ($R^2 \sim 0.5$) and indicate where to take crop samples for analysis prior to applying fertilizer (nitrogen). Using a remote multi-spectral scanner it is possible to estimate dry matter ($R^2 = 0.84$) and shoot %N ($R^2 = 0.88$)[7,8] and these can be used to determine appropriate N fertilizer rates which lead to higher yields.[8,9] This work demonstrated that with NIR-derived data it is possible to increase production per ha, per litre of water and per litre of fuel oil consumed to grow a crop. There are many opportunities for spectroscopists to develop and apply NIR technology to generate data that assists managers of crops and grazing lands to produce more foods and fibres despite the major threats to productivity[10] and the predicted impact of global warming, which threaten to have the greatest impact in the Asian region.[11] It is essential that there is a pool of NIR expertise working at the basic and applied levels across cell, tissue, plant, crop and landscape levels. The benefits of successful applications must be reported and utilized world-wide.

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