



Hyperspectral analysis for automated quantification of total phosphorus in enriched soil samples

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1 Abstract

2 Phosphorus is an essential macronutrient for plant development, and its availability in soil
3 directly influences agricultural productivity. However, traditional laboratory quantification of
4 phosphorus is costly, slow, and destructive. This study introduces a system for automated
5 quantification of total phosphorus (TP) using hyperspectral analysis on soil samples enriched
6 with phosphorus fertilizer (P_2O_5). A previously developed acquisition protocol by the authors
7 was employed, involving the design, development, and construction of a platform equipped
8 with a Bayspec OCI-F camera. The lighting system was designed to ensure adequate spectral
9 response in the visible (VIS) and near-infrared (NIR) regions, covering the range from 420 to
10 1000 nm. A total of 152 soil samples with varying phosphorus concentrations were prepared.
11 From the hyperspectral images (HSI), the spectral response of each sample was extracted. The
12 data were divided into 80% for training and 20% for validation. Partial least squares regression
13 (PLSR) was used to estimate total phosphorus (TP), and Variable Importance in Projection
14 (VIP) analysis reduced the spectral bands from 145 to 78. Subsequently, a forward propagation
15 artificial neural network (ANN) was trained to predict TP content in new samples. The system
16 achieved a coefficient of determination (R^2) of 0.99401, a ratio of performance to deviation
17 (RPD) of 9.1, and a ratio of performance to inter-quartile range (RPIQ) of 13.9, indicating a
18 good fit. Additionally, it achieved a mean absolute percentage error (MAPE) of 12.1% and a
19 root mean square error (RMSE) of 7426 ppm, demonstrating reliable estimation of total
20 phosphorus in soils.

21

22 2. Introduction

23 Agriculture is a fundamental activity worldwide, as it is the primary source of food for
24 humanity. [1,2]. The proper growth of crops in agricultural soils requires a balance of
25 macronutrients, including nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur.
26 These nutrients are essential for protein synthesis, chlorophyll production, and photosynthesis,
27 as well as for the development of roots, leaves, and stems. [3]. The determination and control
28 of these nutrients in the soil optimize metabolic processes, crop production, and crop health,
29 minimizing environmental impact and reducing production costs. [4]. Total phosphorus (TP)
30 is a fundamental indicator for understanding the biological and chemical properties of soil, and
31 is essential for plant growth and the maintenance of life on earth. [5].

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