Overcoming hyperspectral data gaps with generative models to improve machine-learning crop stress detection for crop management

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Hyperspectral imaging (HSI) provides detailed reflectance information across hundreds of wavelengths, enabling early identification of crop changes related to nutrients, disease, and environmental conditions. This level of spectral detail has strong potential to support modern crop management, particularly for timely decision-making in nutrient programs and monitoring subtle plant responses. However, collecting large and diverse HSI datasets is costly, time-consuming, and highly dependent on controlled field conditions. These limitations restrict the development of reliable machine-learning tools that require substantial and varied training data.

This study examines the use of generative artificial intelligence models as a strategy to overcome HSI data scarcity. Using hyperspectral images of Buttercrunch lettuce grown under different nitrogen levels, we evaluated several augmentation methods, including variational autoencoders (VAE), deep convolutional GANs (DCGAN), Wasserstein GANs, and traditional noise-based techniques. Additive and multiplicative noise preserved the original spectral shape but contributed minimal useful variability. In contrast, VAE and DCGAN generated smooth, realistic hyperspectral signatures that closely resembled true plant spectra while increasing dataset diversity.

By enhancing the availability of representative hyperspectral data, generative modeling can strengthen the development of machine-learning tools for crop monitoring, nutrient assessment, and broader crop-management applications. This approach supports more data-informed, proactive management decisions within agricultural production systems.

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