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Using hyperspectral reflectance to evaluate the impact of irrigation and fertilization on mint

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Abstract. In agriculture, water and fertilizer are two limiting elements of plant growth. Indeed, the lack or the excess of one of them disturbs the yields in terms of quality and quantity. Optimal irrigation/fertilization and precisely dosed nutrient supply allow fast-growing plants to reach their full potential, offering much larger and better quality yields. To monitor agricultural crop characteristics, Hyperspectral remote sensing provides an opportunity for an efficient nondestructive method. In this paper, we present a method for smart management of water irrigation and fertilizer using remote sensing. For this purpose, a protocol has been developed to detect the effects of nitrogen nutriments and water supply on potted mint by using UV-PIR field spectroscopy. Results suggest hyperspectral remote sensing has great promise to perfect smart agriculture. In fact, with this method, the effect of nutriments and water supply have been clearly detected.

Key words: agriculture, field spectroscopy, mint, nitrogen, nutriments, remote sensing, water.

INTRODUCTION

Covering a large part of every continent and the first link in the food chain as a producer of organic matter, vegetation is a fundamental component of terrestrial ecosystems. Therefore, monitoring them is essential to keep the ecosystem in balance. Water and fertilizer are two limiting elements of plant growth, the lack or the excess of one of them disturbs the yields in terms of quality and quantity.

Now, water resources are becoming scarce in the whole world. Thus, the use of those resources for agricultural production becomes more difficult (Kalyanaraman et al., 2022). This water-saving policy affects plant hydration and health; therefore, farmers must establish specific irrigation schedules.

Indeed, the biophysical responses of plants to drought exhibit temporal variability, and it is imperative to use a variety of reaction indicators to evaluate the timing of drought impacts, as emphasized by Miller et al. (2022) in their study. The effects of drought become apparent in vegetation that has encountered varying duration of drought stress and has been exposed to different seasonal conditions.

Like water, fertilizer's deficiency for optimum plant growth is common. In fact, modern farming requires that farmers apply fertilizers based on the crop's absorption capacity and nutritional needs. This approach aims to optimize nutrient efficiency, ensuring a profitable use of resources while minimizing environmental runoff (Albornoz, 2016). Fertilizers are composed of three essential macroelements, namely nitrogen (N), phosphorus (P), and potassium (K); each of which has a different influence on the plant's physiology and pathology.

In fact, nitrogen availability in the soil profoundly influences both crop yield and the quality of the harvest in most annual crops, nitrogen (N) is regarded as a crucial plant nutrient. During the vegetative growth stage, plant roots absorb soil nitrogen, which is then assimilated in the leaves to synthesize proteins. These proteins play vital roles in forming structural components, such as cell walls, or participate in various metabolic pathways as enzymes. In leaves, a substantial portion of the nitrogen is primarily engaged in the photosynthetic process, notably through the enzyme RuBisCO, which accounts for approximately 50% of the nitrogen content in leaves as noted by Evans (1983). It is also allocated to enzymes involved in the transport and assimilation of fixed carbon. For this reason, researchers have previously found that crop yield increased with the addition of nitrogen (Zhou et al., 2021). Therefore, the farmers used to oversupply nitrogen to have a perfect crop yield. However, contrary to their expectations, this over-fertilization has led to serious environmental problems, such as pollution of soil and groundwater (Yi et al., 2020) and yield losses and reduction in the quality of agricultural products (Albornoz, 2016), those results also were confirmed by Naseri & Hemmati (2017).

In order to optimize the use of irrigation water and fertilizers, plant deficiencies need to be properly assessed. In fact, there are two types of methods for take-out phenotypic information of crops: manual and remote sensing methods. The first one requires the instrument operators to perform intensive field collection and is therefore destructive, effortful, and time-consuming. In contrast, remote sensing methods can cover large areas and are non-destructive means for phenotypic crops (Deng et al., 2018).

In recent years, numerous researchers have used satellite-based remote sensing methods to study crops. For example, Moderate Resolution Imaging Spectroradiometer (MODIS) multi-time series vegetation indices (VIs) have been used to investigate crop yields, traits, and growth conditions during various phenological stages (Sakamoto et al., 2010; Sakamoto et al., 2013). In fact, these studies develop a corn grain yield estimation model using MODIS-based Wide Dynamic Range Vegetation Index (WDRVI) ($\alpha = 0.1$), integrating the 'Shape Model Fitting method (SMF),' a MODIS-based technique for detecting crop phenology.

In fact, spectral measurements in the small field are more accurate and reliable, and allow verification of spatial remote sensing data (Turner et al., 2003). As a result, spectroscopy is an ideal method for setting up a database or carrying out a scientific study. Therefore, to assess plant growth, Liang et al. (2015) have developed a method that combines hyperspectral VIs and a hybrid inversion method to estimate the LAI rapidly and non-destructively. In addition, Mistele & Schmidhalter (2008) have described the nitrogen nutriment using spectral measurements. Also, Straumite et al. (2015) use a spectrophotometer JENWAY 6300 to analyze the pigment content in the leaves and the stems of different varieties of mint.

This paper introduces a method to efficiently manage water irrigation and fertilizer application through remote sensing by establishing a protocol to identify the impacts of nitrogen nutrients and water supply on plants. It addresses the feasibility of detecting phenotypic changes in mint due to water and nitrogen supply using UV-NIR spectroscopy, both independently and in combination.

The plant subject of the experiment is mint. Since mint holds significant importance in Moroccan culture, it serves as a valuable and essential crop that is widely consumed. It is a fragrant perennial characterized by vibrant green, wrinkled leaves that offer a robust, sweet, and refreshing taste (Bamouh, 2008).

MATERIALS AND METHODS

This experiment consists of planting mint (Species: Mint, Variety: Green, Seeds: Standard) in pots and following a protocol in which the quantities of water and nitrogen added to the pot are varied, to monitor the response of reflectance. This plant was chosen because it has a reduced cycle so it grows and reproduces very fast, and due to its green leaves, it reflects easily the absorption of water and fertilizer added during its cycle (Bamouh, 2008). The study was conducted in the laboratory of the University of Sciences and Technology of Tangier in northwestern Morocco (coordinates: Long = - 5.89428561° / Lat = 35.73571077°).

Experiment description

The experiment was conducted winter period. The mint was planted in pots on December 25, 2022 with an optimal initial water supply. From December 29, 2022, the protocol has been started by adding water and nitrogen supply (Table 3) after taking spectral measurements of each pot twice a week.

The measurements were taken at 1 a.m. twice per week. In order to ensure accurate measurements, the work environment and external parameters (such as: temperature, brightness, wind, humidity): were fixed and limited as possible (TAIA et al., 2023). To assure this, just before each spectral measurement is made, the ambient temperature of the laboratory was taken using a thermometer and the cloud cover situation was noted from the meteorological site since it affects the brightness of the room. Table 1 presents the meteorological conditions at the time of measurement.

Table 1. Temperature and weather conditions at the time the measurements were taken

Months	Dec	Jan						Feb					
Days	29/12/2022	01/01/2023	05/01/2023	12/01/2023	15/01/2023	19/01/2023	26/01/2023	02/02/2023	05/02/2023	09/02/2023	12/02/2023	23/02/2023	26/02/2023
Time	13 h	13 h	13 h	13 h	13 h	13 h	13 h	13 h	13 h	13 h	13 h	13 h	13 h
T °C	18	20	18.6	21.5	21	15.8	19.3	20.2	20.1	18	20.5	14	17
Cloud cover	Little cloud	Little cloud	Partly cloudy	Partly cloudy	Little cloud	Little cloud	Cloudless	Little cloud	Cloudless	Cloudless	Little cloud	Cloudy	Partly cloudy

In order to understand and interpret the results obtained through spectroscopy, Table 2 shows fixed and variable elements according to the case:

Table 2. Sample cases

	Water	Nitrogen
Case No 1	variable	fixed according to the producer of fertilizer
Case No 2	fixed according to plant water requirements (Eq. 1)	variable
Case No 3	variable	variable

The crop water requirement is calculated by the following formula (FAO, 2021):

$$B_{brute}(mmj^{-1}) = ET0 * K_r * K_C \div E \tag{1}$$

where ET0 – reference evapotranspiration (mm d^{-1}); K_r – reduction coefficient; K_c – cultural coefficient.

The meteorological data used for the calculation of the needs are taken from the Regional Office for agricultural development of Loukkos.

The experiment involves growing mint in twelve pots.

The protocol followed is presented in Table 3.

Measurements and data preprocessing

The ASD Fieldspec HandHeld spectrometer was used for the spectral measurement. In fact, the FieldSpec is a highly portable, general-purpose spectroradiometer useful in many applications requiring either the absolute or relative measurement of light energy.

During this experiment, the material used is a UV–NIR spectroscopy (range of 300–1,100 nm), ASD Fieldspec HandHeld spectrometer, with this specific features: Spectral Range: 325–1,075 nm, Spectral resolution: 3.5 nm at 700 nm and Sampling Interval: 1.6 nm. In addition, a calibration was done using a white reference standard. This was done before taking measurements of each sample to ensure that both the unknown and white reference spectra were subjected to the same illumination geometry (David, 1999).

Table 3. Water and nitrogen supply to the mint according to the measurement protocol

Case No	Pot No	Variables	Amount (%)
Case No 1	pot no 1	water	0%
	pot no 2		75%
	pot no 3		100%
	pot no 4		125%
Case No 2	pot no 5	nitrogen	0%
	pot no 6		75%
	pot no 7		100%
	pot no 8		125%
Case No 3	pot no 9	water and nitrogen	0%
	pot no 10		75%
	pot no 11		100%
	pot no 12		125%

The collect and treatment of data was done with The FieldSpec® RS3 software and the curves were shown with FieldSpec® view.

At the time of the measurements, the spectroradiometer has been fixed in the same position: orientation, distance from the target and even the location of Measurements (Fig. 1). The distance between the spectrometer and the plant was from 30 to 40 cm (the spectrometer was fixed, while the distance varies depending on the height of the plant's leaves) Consequently, stray light and random noise are constant throughout the measurements. The computed reflectance is written as (David C, 1999):

$$Computed\ Reflectance = \frac{TrueTargetSignal + StrayLight + RandomNoise}{TrueReflectanceSignal + StrayLight + RandomNoise} \qquad (2)$$

where Stray light – the rays detected by the sensor other than those reflected by the plant and Random noise – noise depends on the device itself.

Noise, which arises from instrument handling and environmental factors, causes random fluctuations around a signal. While reducing noise in spectra is straightforward, doing so without losing valuable information is a challenging task. For our preprocessing, we choose the Savitzky-Golay filter. This smoothing and differentiation filter optimally fits a set of data points to a polynomial using least squares regression. In fact, for a given signal measured at n points and a filter width, w, this filter computes a polynomial fit of degree d within each filter window (Gallagher, 2020). This digital polynomial smoothing filter reduces noise while preserving the prominent peaks in the original spectrum with minimal distortion of spectral features such as peak heights and bandwidths of absorption bands. In our study, we adopted this filter. The Savitzky-Golay smoothing provides the highest accuracy in predicting spectral data compared to other methods based on partial least squares regression (Wei & Li, 2022).

Figure 1. Measuring process.

Due to extremity effects, this filter is usually calculated using the entire spectrum, then excluding the extremities before modeling. The algorithm follows the following simplified equation (Luo et al., 2005):

$$p(x) = \sum_{i=0}^{d} a_i x_i \qquad (3)$$

where *a* – coefficients a0...ad; *d* – degree of polynomial; *x* – reflectance or absorbance point; *p* – polynomial.

RESULTS AND DISCUSSION

Output data before processing

After a series of measurements taken during the first and second experiments, we obtain the graphs in the following figures. Each figure presents a comparison of all pots in special cases of our protocol (Table 3).

Measurements present curves in Figs 2, 3 and 4 with noise and disturbed information, on which special pre-processing must be applied to improve signal quality and also to increase method reproducibility, robustness, and model accuracy.

Case 1: water supply

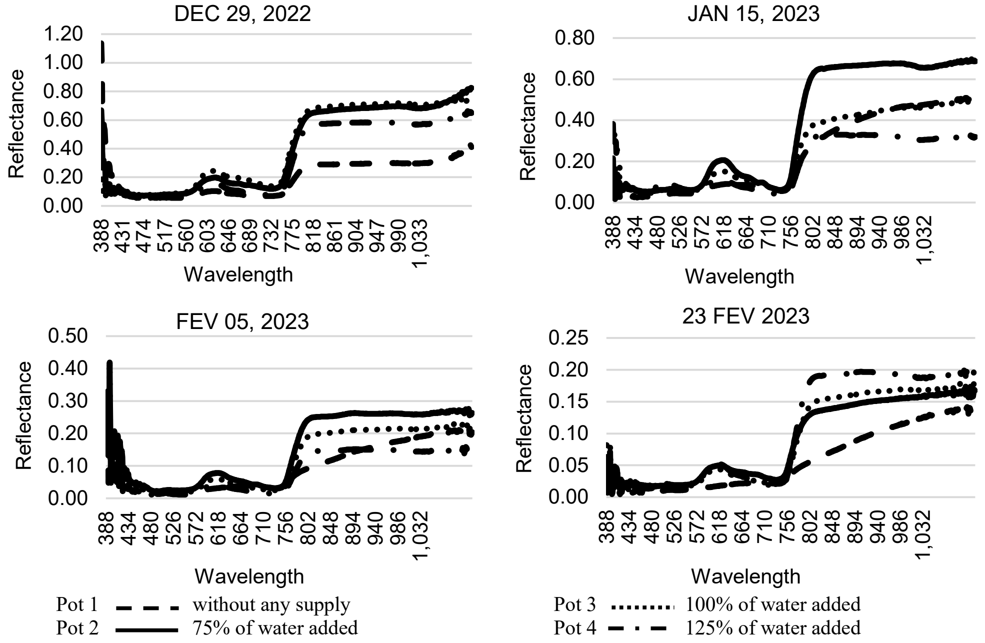

Figure 2. Evolution of mint reflectance with variable water supply (case N°1).

Case 2: nitrogen supply

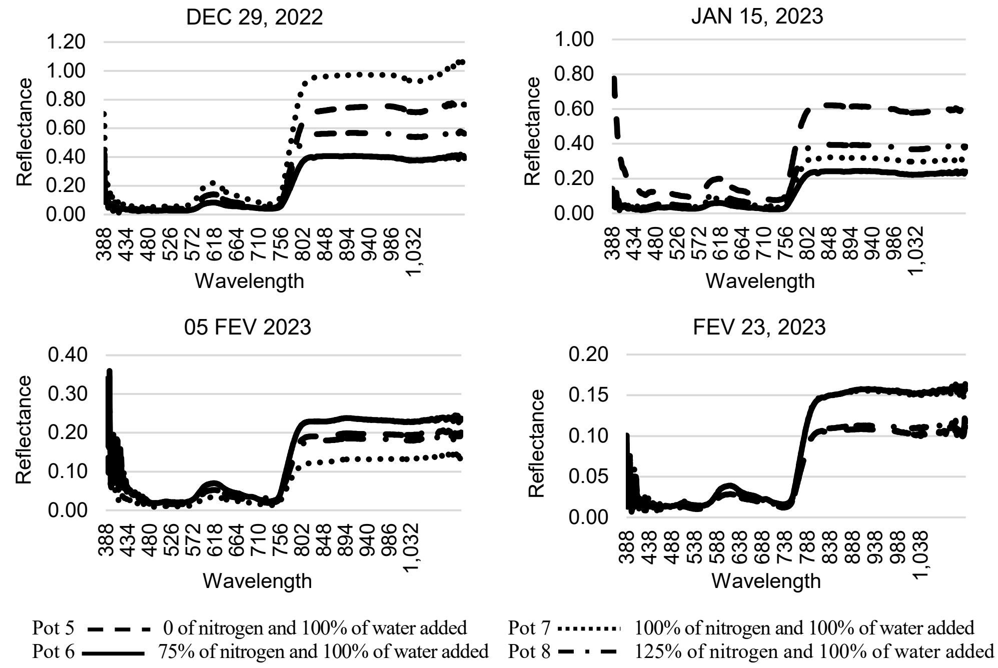

Figure 3. Evolution of mint reflectance with variable nitrogen supply (case N°2).

Case 3: nitrogen and water supply

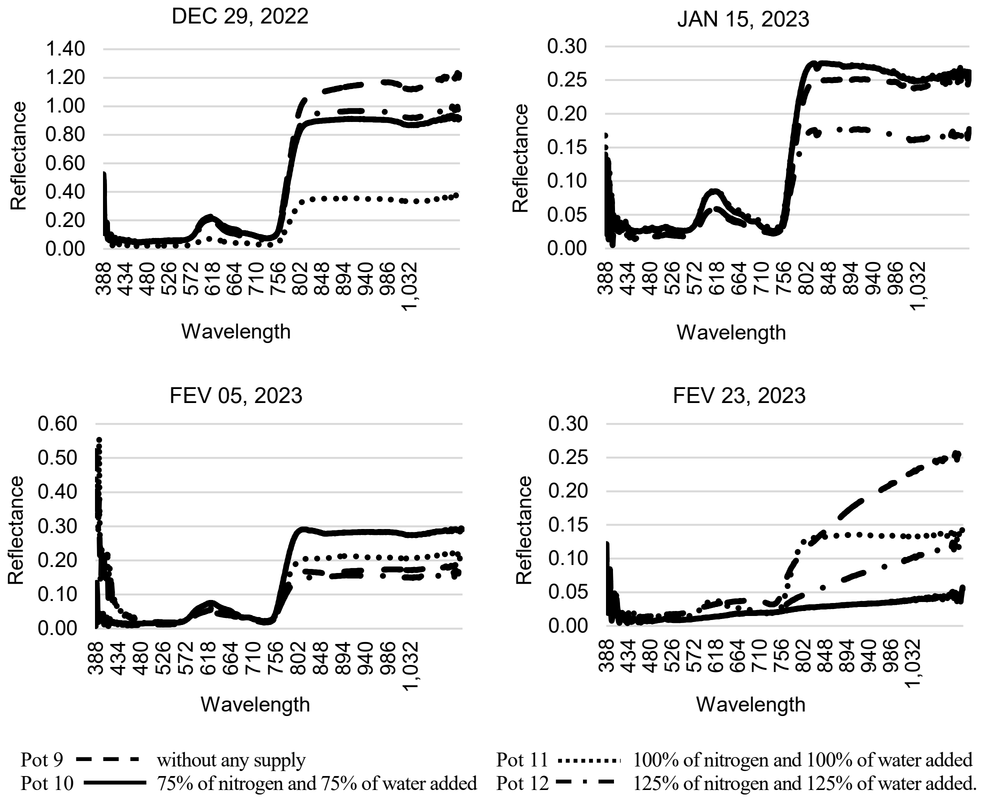

Figure 4. Evolution of mint reflectance with variable nitrogen and water supply (case N°3).

Output data processed

In our study and in order to reduce noise in raw output data, we adopted the Savitzky-Golay smoothing. This filter provides the highest accuracy in predicting spectral data (Wei & Li, 2022).

After the application of the SG filter, the curves are remarkably smoothed with correct pre-processing, without losing the information conveyed by the curves.

A plant's needs for water and fertilizer depend on the plant's phenological stage not just on weather conditions.

Case 1: water supply. Analyzing the curves in Fig. 5 based on the wavelength domains, it is remarkable that in the visible domain, the curves contain a peak around 460–700 nm, which is due to chlorophyll (green colour of leaves). And which starts to flatten over time due to plant withering. In addition, regarding the near-infrared domain that reflects the plant structure, the reflectance values change randomly and tend towards zero, which can be interpreted as the destruction of the leaf structure (Satterwhite & Henley, 1990).

The case 1 (Fig. 5) presents pots with water supply variation. In fact, the last water supply was added to the pots on December 29, 2022 (initial state), and since then, pot No 1 has not received any further water supply. As a result, the plant will undergo wilting. The physiological transformations associated with the plant's growth, from the maturation phase to senescence, whether prompted by natural factors such as phenological stages or stress-related factors, significantly affect the spectral responses of vegetation (illustrated in Fig. 3 pot No 1). During autumn, for instance, plants decrease their photosynthetic activity, and chlorophyll pigments disappear, allowing other leaf pigments to manifest their colors. Cells gradually enter a state of plasmolysis, resulting in the destructuring of cell layers. Consequently, there is a noticeable rise in reflectance in the visible wavelengths (yellow-red), coupled with a simultaneous decline in reflectance in the NIR. (Li & Guo, 2014). Whereas, pots 2, 3, and 4 receive a different quantity of water in such a way that the supply in pot 2 is less than the supply in pot 3 and both are less than the supply of pot 4. The lack of water supply is clearly seen in the red edge domain, which refers to the region of rapid change in reflectance of vegetation between the red and the near-infrared range of the electromagnetic spectrum. The measurements of plant in pot one showed a gradual change, instead of rapid one, in the reflectance in near infrared what indicates the destruction of leaves internal structure.

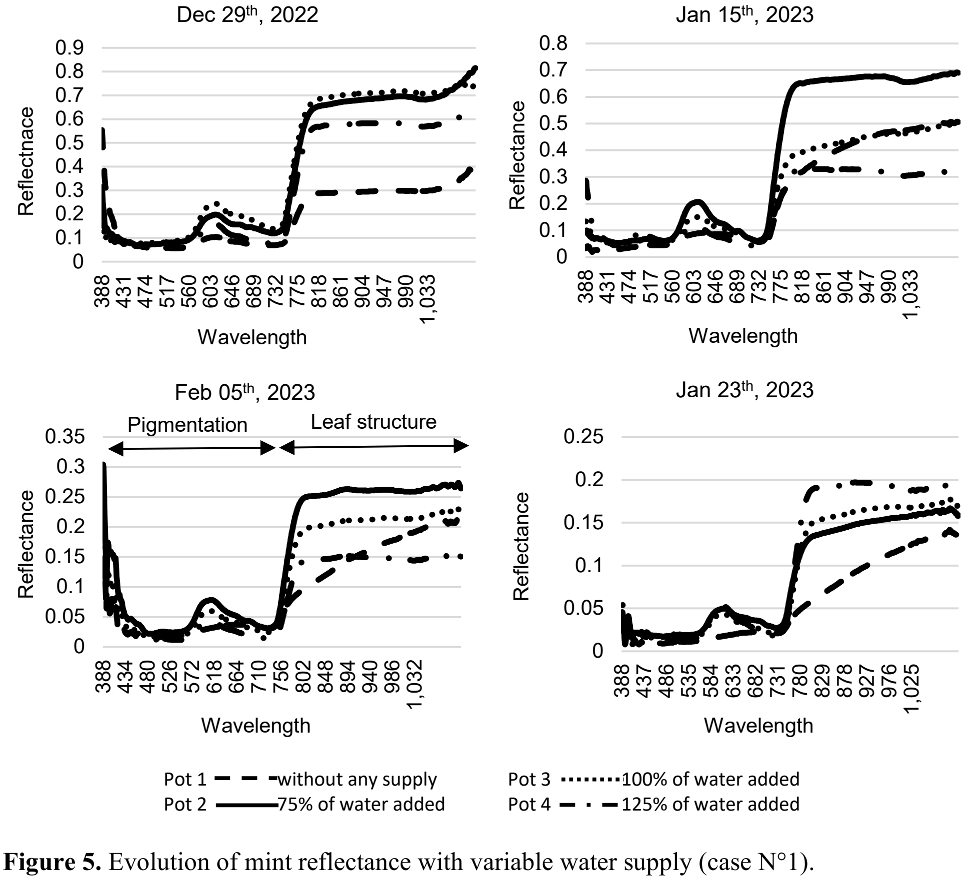

Figure 5. Evolution of mint reflectance with variable water supply (case N°1).

Looking at the latest measurements from February 23, 2023, we can see that reflectance is proportional to the amount of water added to each pot in case No 1 (reference value of pot 1 < pot 2 < pot 3 < pot 4). This has been demonstrated by El Azizi et al. (2022) study which compared reflectance between two periods (July 2021 and March 2022), concluding that reflectance in March after a series of precipitations is greater than reflectance in July throughout the visible and NIR region.

Case 2: nitrogen supply. Fig. 6 shows case No 2 of the protocol with nitrogen as the variable element. The above curves show that pots with nitrogen have a higher reflectance than those without and the potted mint with the highest nitrogen input reacted less with the sun's rays. This is due to the effect of nitrogen on the plant, as the main nutrient for vegetation; which directly affects the greenness and structure of the leaves. However, an excess of this nutrient negatively affects the plant's physiology and pathology (Lemaire et al. 2008; Naseri & Hemmati, 2017). This agrees with a lot of research; Mistele & Schmidhalter (2008); which concluded that spectral measurements were advantageous to describe the nitrogen nutriment and they appear to correlate well with this important fertilizer.

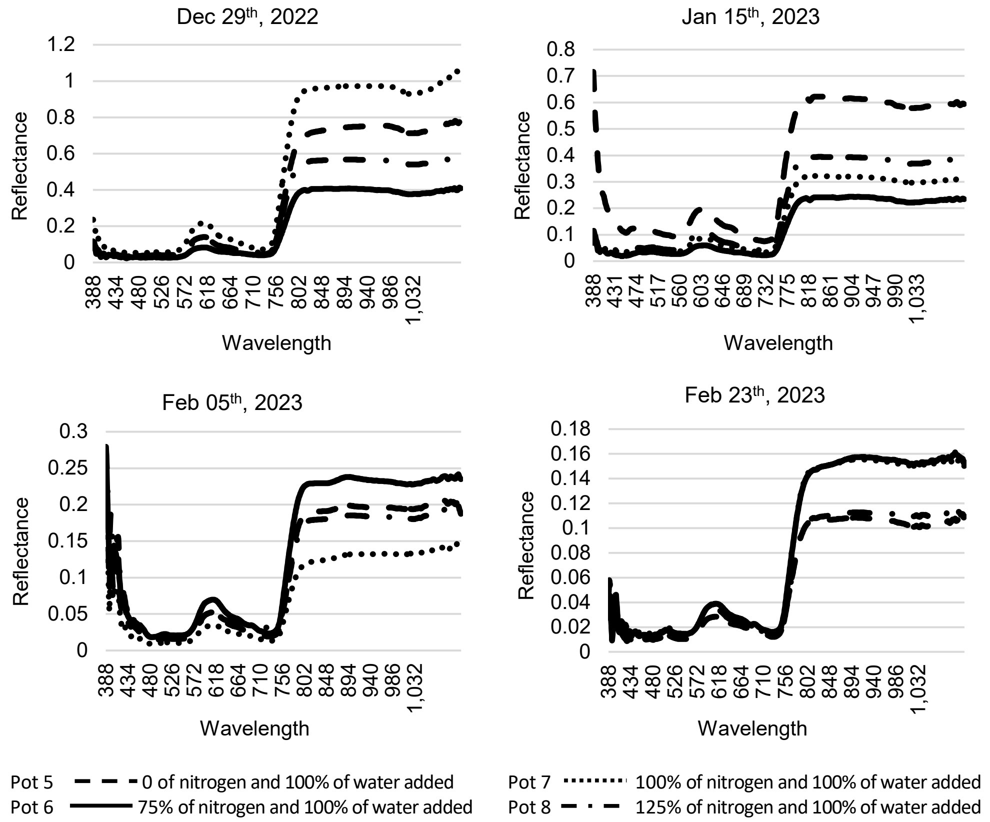

Figure 6. Evolution of mint reflectance with variable nitrogen supply (case N°2).

The measurements indicate that both under- and over- fertilisation leads to plant stress observed in low reflectance in near infrared, which is related to poor leave structure. The slower degradation of leaves structure was obtained using 75% of the recommended nitrogen doses.

Case 3: nitrogen and water supply. Fig. 7 shows the combined variation of water and nitrogen illustrated in case No 3. The curves numbers illustrate that pots with nitrogen and water supply have a higher reflectance than those without and the potted mint with the highest nitrogen and water input reacted less with the sun's rays.

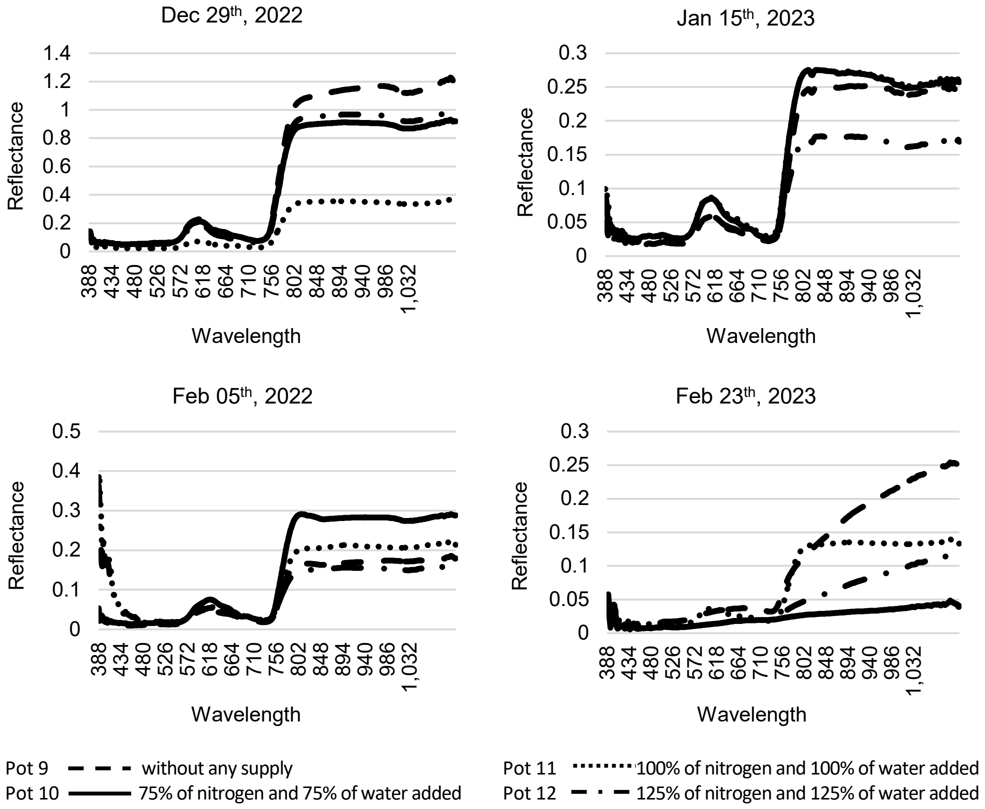

Figure 7. Evolution of mint reflectance with variable nitrogen and water supply (case N°3).

The last water supply was added to the pots on December 29, 2022 (initial state), and since then, pot No 9 has not received any further water supply. As a result, the plant underwent wilting. The physiological transformations associated with the plant's growth, from the maturation phase to senescence, whether prompted by natural factors such as phenological stages or stress-related factors, significantly affect the spectral responses of vegetation (illustrated in Fig. 7 pot No 9).

CONCLUSIONS

Methods of hyperspectral remote sensing of biophysical and biochemical characteristics of crops have promise in improving the management of agricultural production. Here, we aimed to detect the effect of water and nitrogen supply on the mint pot using hyperspectral remote sensing. We found that there is a remarkable effect of this nutriments supply in vegetation using field UV–NIR spectroscopy and without destruction of the plant.

As a result, the reflectance reflects the leaf pigmentations and structure of our plant as confirmed by other studies, as well as these pigmentations and structure are directly linked to water and nutriments added to the plant; we demonstrate by this study that there is a relation between reflectance and the two elements studied. Consequently, the experiment emphasizes the importance of using spectroscopy to monitor plant growth. The conclusions provided principal future improvements and contributions to precision agriculture. This work aims to develop a tool for monitoring water and fertilizers supply.

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