

Reflectance spectrometry applied to the analysis of nitrogen and potassium deficiency in cotton¹

Espectrometria de reflectância aplicada à análise das deficiências de nitrogênio e potássio em algodoeiro

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ABSTRACT - The detailed study of hyperspectral data that optimise the management of agricultural inputs can be a powerful ally in the nutrient diagnosis of plants. This study characterised variations in the reflectance factors of cotton leaves (*Gossypium hirsutum* L.) of the BRS 293 cultivar, submitted to different levels of N and K fertilisation. A total of 166 plants were submitted to four doses of N and K, with twenty replications and six controls. Each treatment represents one level of fertilisation: 50, 75, 100 and 125% of the recommended amount of both macronutrients at each stage of the phenological cycle. The spectroradiometer used in the laboratory was the FieldSpec Pro FR 3[®] with a spectral resolution of 1 nm and an operating range that extends from 350 to 2500 nm. In both treatments, PCA allowed wavelengths to be identified grouped by such parameters as brightness, chlorophyll and leaf moisture. The N and K fertilisation caused significant changes in the factors, where the greatest difference between doses was seen at 790 and 1198 nm. The wavelengths between 550 and 700 nm and at 1390 and 1880 nm were, respectively, the most promising for explaining the variance in nutrient levels of N and K in cotton.

Key words: Remote sensing. Hyperspectral sensor. Mineral Deficiency. *Gossypium hirsutum* L..

RESUMO - O estudo minucioso de dados hiperespectrais pode ser um forte aliado para o diagnóstico nutricional de plantas e otimizam o manejo de insumos agrícola. Este estudo caracterizou as variações dos fatores de reflectância em folhas de algodoeiro (*Gossypium hirsutum* L.) da cultivar BRS 293, submetidas a diferentes níveis de adubação de N e K. Foram cultivadas 166 plantas submetidas a quatro doses de N e K, com vinte repetições e seis controles. Cada tratamento se referiu a um nível de adubação: 50, 75, 100 e 125% da quantidade recomendada para ambos macronutrientes em cada etapa do ciclo fenológico. O espectrorradiômetro utilizado em laboratório foi o FieldSpec Pro FR 3[®] com resolução espectral de 1 nm e cuja faixa de operação se estende de 350 a 2500 nm. Em ambos os tratamentos, a ACP permitiu identificar os comprimentos de onda agrupados em parâmetros como o brilho, a clorofila e a umidade das folhas. A adubação de N e K provocou alterações significativas nos fatores, onde a maior diferenciação entre as doses se deu aos 790 e 1198 nm. Os comprimentos entre 550 e 700 nm e em 1390 e 1880 nm se mostraram, respectivamente, as mais promissoras para explicar a variância dos níveis nutricionais de N e K sobre a cultura do algodoeiro.

Palavras-chave: Sensoriamento remoto. Sensor hiperespectral. Deficiência Mineral. *Gossypium hirsutum* L..

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INTRODUCTION

The management of nutrient levels, especially of nitrogen, phosphorus and potassium (NPK), is an essential factor in obtaining high productivity and improving the quality of fibre. The production costs of herbaceous cotton (*Gossypium hirsutum* L.) are high, and for cotton production to be economically viable, it is essential to employ techniques that optimise the use of these inputs.

According to studies by Motomiya, Molin and Chiavegato (2009), N deficiency is very common in this crop, due to the losses resulting from the high demand for the element. These losses lead to less biomass production and premature senescence, evidenced as chlorosis of the older leaves, which tends to extend visibly to the entire plant. The need for K, which is also high (ROSOLEM, 2012), is usually expressed in the canopy as internervous and marginal chlorosis in the older leaves, progressing to the newer leaves due to the low concentrations of leaf chlorophyll.

Although, from the perspective of Precision Agriculture, there are several techniques for the nutrient assessment of crops, those that use spectral reflectance have gained a lot of ground in commercial environments due to the ease of correlation between various optically active nutrients (WANG; WEI, 2016) and reflectance factors, among which nitrogen (N) and potassium (K) stand out. For this reason, RS techniques are used by agricultural companies, not only to observe spatial and phenological variations in these elements, but to act immediately to supplement them in the amount required by the cotton.

Faced with such challenges, Corti *et al.* (2017), describe RS as a non-destructive technique to estimate the biophysical characteristics of vegetation. The most important wavelengths can be broken down, since changes in the biochemical composition, nutrient concentration and cell turgor of the leaves trigger distinct and characteristic levels of energy absorption.

The leaf is the principal organ of the vegetation that is subject to electromagnetic radiation (JENSEN, 2011). When solar radiation falls on the canopy, each leaf intercepts the incident radiant flow (ϕ_i); this electromagnetic energy interacts with the pigments, water and intercellular spaces inside the leaf, triggering three physical paths: reflection, absorption and transmission. Depending on the leaf structure, these paths have different intensities (LIU *et al.*, 2015), building, point by point, a particular factor curve.

Multispectral analysis, such as those by Schlemmer *et al.* (2013), showed wavelengths, especially those in the green region (550 nm) and NIR (730 nm), as the

most correlated with leaf nitrogen concentrations, while Ponzoni, De and Gonçalves (1999) showed that potassium deficiency can be detected spectrally in the visible region of the spectrum (VIS). However, this approach is still limited when aiming to detect more-precise physical correlations between nutrient concentrations and spectral factors. As such, a hyperspectral analysis contains a wealth of detail, and can discriminate individual wavelengths relevant to these correlations which would be imperceptible under multispectral inspection.

Therefore, with the aid of the tools available to Hyperspectral RS and Multivariate Statistics, this study sought to identify sensitive areas of the electromagnetic spectrum reflected by cotton leaves in the laboratory, as well as to determine the wavelengths directly influenced by N and K fertilisation, highlighting the effect of their particular characteristics on the crop.

MATERIAL AND METHODS

The work was carried out in a greenhouse located in the experimental area of the Hydraulics and Irrigation Laboratory of the Agricultural Engineering Department at the Federal University of Ceará, Pici Campus, in the city of Fortaleza, located at 3°45' S and 38° 33' W at an approximate altitude of 19 meters. According to the Köppen classification, the climate in the region is type Aw', tropical, with a dry season during the winter. As the crop was planted between 2 May and 3 September 2018, it was necessary to ensure that there was no interference from the strong rainfall recorded in the area.

In order to guarantee that the level of fertilisation in each treatment was correct, the crop was grown in low-density polyethylene pots with a capacity of nine (09) litres (0.25 x 0.18 x 0.20 m), which were filled with a sandy soil (arisco), the only inert material to provide physical support to the root structures. Each treatment was submitted to the same daily irrigation depth based on the water requirement of the crop at each stage of development, as per Ferreira and Carvalho (2005). The water was divided between the 166 pots using self-compensating Katif® drippers, at an application rate of 3.75 L.h⁻¹.

After preparing the system, cotton plants (*Gossypium hirsutum* L.) of the BRS 293 cultivar were grown for 119 days in an open-sided agricultural greenhouse. The design was completely randomised (CRD), in a scheme of eight (08) treatments with twenty (20) individual replications. Each treatment comprised one level of nitrogen or potassium fertilisation, with the nitrogen applied to each replication at a dose of N1 = 50%, N2 = 75%, N3 = 100% or N = 125% of the amount of N recommended at each stage in the phenological cycle.

Similarly, the levels of potassium comprised K1 = 50%, K2 = 75%, K3 = 100% and K4 = 125% of the amount of K⁺ required at each stage.

As recommended by Ferreira and Carvalho (2005), the nutrient demand of the crop throughout the complete cycle, i.e. 100% of the demand for each element, is 69 kg.ha⁻¹ N, 26 kg.ha⁻¹ P, 73 kg.ha⁻¹ K and 36 kg.ha⁻¹ Ca, 27 kg.ha⁻¹ Mg, 6 kg.ha⁻¹ S and 30 kg.ha⁻¹ FTE BR12 fertiliser (Fe, Cu, Zn, Mn, B and Mo). The treatments were distributed so that fertilisation was uniform in all 166 replications, with variations in the percentage of N and K only. As such, four (04) direct fertilisation events were carried out throughout the cycle (20, 41, 67 and 107 DAE). Urea (CO(NH₂)₂) and potassium Chloride (KCl) were used as the sources of N and K respectively.

To obtain the hyperspectral data, the laboratory, 92 metres from the greenhouse, was completely covered in black, so that no light fell on the samples during the readings except from the halogen lamp employed in the experiment. The FieldSpec Pro FR 3[®] spectroradiometer (Analytical Spectral Devices) was used; it has three sensors with the spectral resolution resampled to 1 nm, and an operating range that covers the Visible, Near Infrared (NIR) and Shortwave Infrared bands (SWIR), that together include data from 350 to 2500 nm (ANALYTICAL SPECTRAL DEVICES, 2010). The receiver of the optical sensor is positioned perpendicular to the leaves, and operational control is managed by a computer that stores and converts the physical data to numeric.

Sampling the individuals was standardised to the time of flowering when the reproductive system was active in 70% of the crop. In all 166 plants, analysis was standardised to the third leaf on the first formed

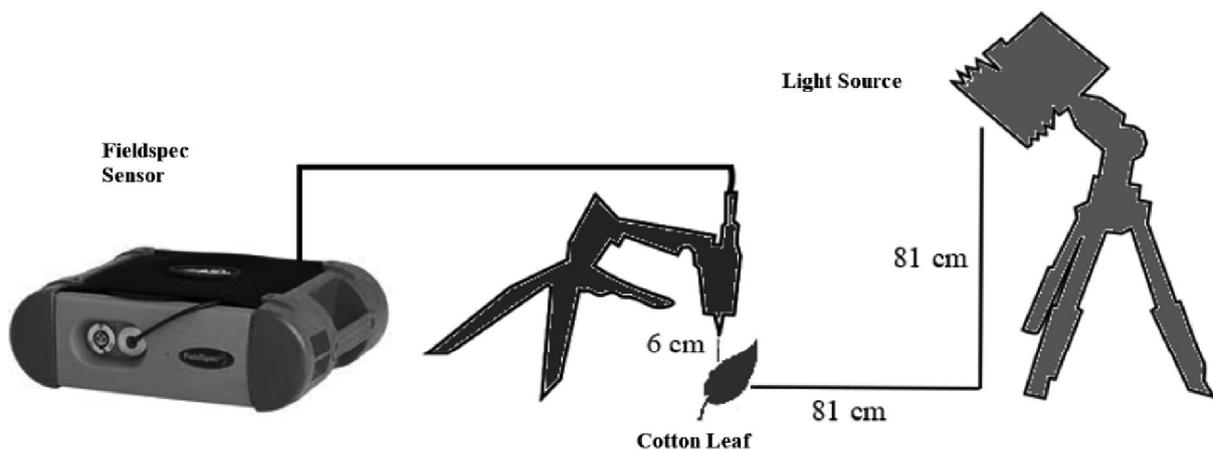
reproductive branch. Selecting this leaf allowed any symptoms of N and K deficiency in the first reproductive branch of the plant to be uniformly evaluated, considering the natural displacement of each nutrient from the oldest to the youngest leaves under deficiency. The leaves were packed in insulating material, taken from the field to the laboratory (dark-room), and duly identified within the set of 20 replications.

The data were acquired from 15:00 to 17:30, the least stressful time of day regarding the plants being damaged during collection, given that water loss to the atmosphere would not be so intense during the following hours. The equipment was placed on a dark bench, with the halogen lamp (50 W), whose beam was collimated along the target plane, positioned at a distance of 81 cm, forming a zenith angle of 45° incidence on the leaf. The leaf tissue was placed 6 cm from the orthogonally fixed sensor (Figure 1), adapting the standard acquisition geometry described by Moreira, Teixeira and Galvão (2014), with the distances optimised for reading vegetation.

Three readings were taken on the adaxial surface of the leaf in each sample; the simple arithmetic mean of the readings was determined in each leaf from these digital values. The digital values were then converted to the reflectance factor of each sample using the ViewSpec Pro[®] v6.2.0 software (ADS Inc).

With the aim of optimising the signal to noise ratio, the reflectance data were submitted to smoothing using a window of three consecutive data. In this study, the moving-average technique was chosen so as to inspect each part of the spectral profile preserving specific variations from the different applications of potassium and nitrogen. The dimensionality of the variables under study was then reduced through transformation, using Principal Component Analysis (PCA), which enabled the original

Figure 1 - Acquisition geometry with the FieldSpec Pro FR 3, in a dark environment



set of data to be transformed into new variables, i.e. the Principal Components - PC, with no loss in their capacity to represent the structure, as highlighted by Mishra *et al.* (2017) and Lara *et al.* (2013), investigating hyperspectral data in vegetation.

The PCs were constructed using the SPSS® v20 software, and presented as scree plots of the respective explained variance, while the loadings and coefficients of the prioritised PCs were inspected to quantify the contribution of each band of the spectrum into oscillation patterns. It was possible to identify the Components generated by the linear combination of reflectance factors and the concentrations under study, together with their spectral variance, (ROCHA NETO *et al.*, 2017). Three important parameters were generated: i) eigenvalues, which refer to how much of the variance can be represented by each Component; ii) eigenvectors, which highlight the most-relevant input variables to any one Component; and iii) loadings, which demonstrate the influence of each wavelength on the composition of the PC (JIA *et al.*, 2020).

RESULT AND DISCUSSION

The smoothed medians for all treatments are shown in two graphs, where the oscillations give an idea of the behaviour of each treatment with N (Figure 2) and K (Figure 3). In the visible region, the vegetation

displayed lower reflectance factors compared to the IR, with absorption nuclei centred on the blue (470 nm) and red (670 nm). This result is in line with the study by LIU *et al.* (2017), since, as chlorophyll has a unique biochemical structure, the spectral absorption caused by its electronic transition is usually located in the visible light region.

In the fertilisation treatments with nitrogen, progressively greater reflectance factors were seen in regions typically correlated with the concentration of chlorophyll (550 nm), with a coefficient of variation (CV) between the minimum and maximum values of 11.8% (upward trend). When potassium was the nutrient (Figure 3), there was an increase of 9.68% in this same region, reinforcing the relevance of both macronutrients for the proper functioning of photosynthetic tissue, albeit highlighting the effects of the nitrogen.

Smaller rises were seen in the bands corresponding to the NIR plateau at 730-900 nm, which represents the structure of the leaf mesophyll (SOUZA *et al.*, 2020). For fertilisation with N and K, the measured coefficients of variation were 2.11% and 3.69% within each group respectively. Under these laboratory conditions, the maximum reflectance factors reached 77% in the treatments with nitrogen and 71% for potassium in the regions of maximum levelled value, from 800 to 1100 nm.

For the water content in the leaf tissue, described by Cheng, Rivard and Sánchez-Asofeifa (2011) as having

Figure 2 - Median of the hyperspectral reflectance factors of cotton-leaf tissue fertilised with nitrogen and submitted to smoothing

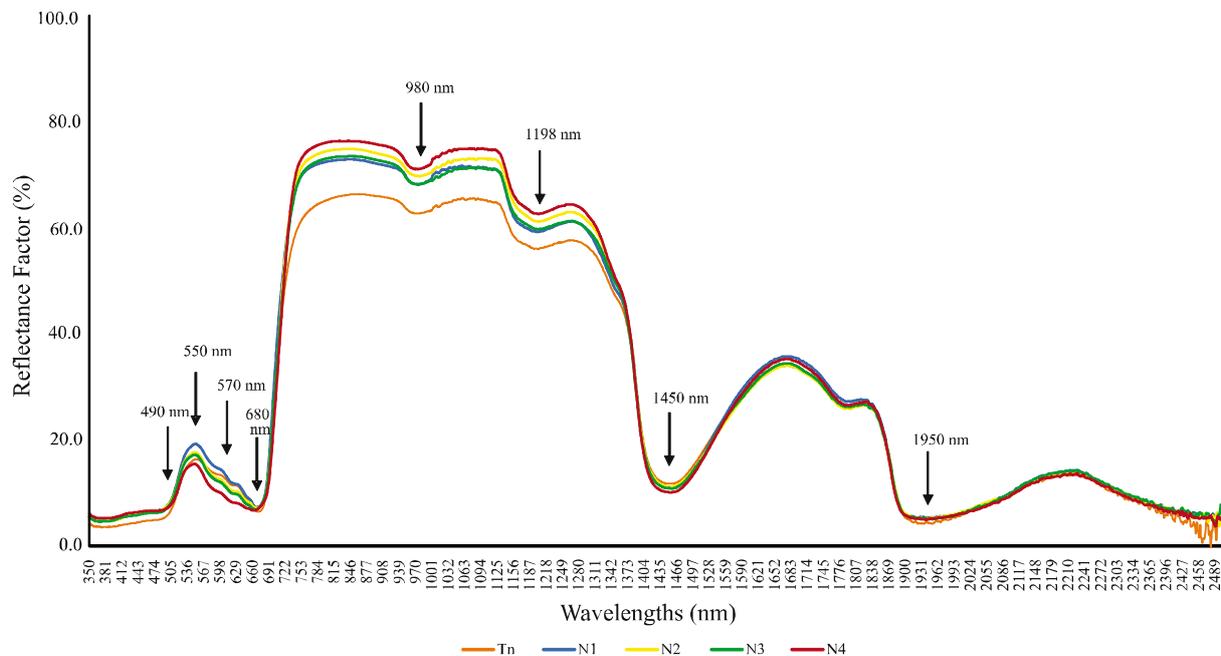
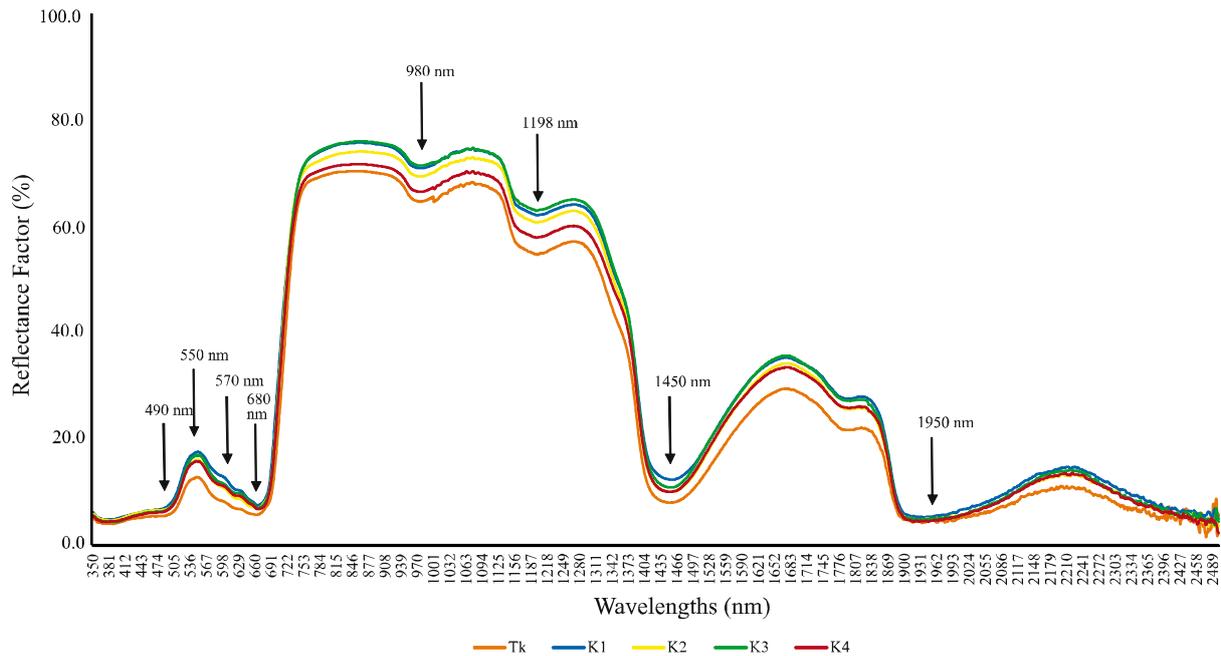


Figure 3 - Median of the hyperspectral reflectance factors of cotton-leaf tissue fertilised with potassium and submitted to smoothing


absorption troughs centred at 980, 1198, 1450 and 1950 nm, a variation of 6.34% when applying nitrogen and 10.06% when applying potassium were found between the extreme values. For the wavelengths typically associated with lignin, starch and protein (1690 nm) (JENSEN, 2011), the mean CV for nitrogen fertilisation was 2.26%, while potassium fertilisation resulted in a CV of 3.32% for this same band.

When analysing the visible range of the electromagnetic spectrum, the greatest peak in reflectance was found at around 550 nm for nitrogen, corresponding to the green region of the visible spectrum, which explains the greening of the leaves that occurred in treatment N1 (N = 50%), with 19.2% reflected energy. Such an intriguing response may be associated with this also being the treatment with the highest reflectance factor in the yellow band (560 to 590 nm) (NOVO, 2008), balancing out the leaf pigments and appearing less green than replications at higher doses. As found by Cilia *et al.* (2014), plants subjected to nutrient stress trigger a natural degradation of their active pigments, with a consequent increase in reflectance in the visible region. The controls with no fertilisation (N = 0%) showed a lower proportion of green (490-560 nm) (NOVO, 2008) and the second highest values for yellow (560 to 590 nm), a fact that left them noticeably different from the other cotton plants in the study.

Two typical absorption wavelengths were seen, centred around 480 nm and 680 nm. Both are closely related

to the presence of photosynthetic pigments (chlorophylls a and b, and carotenoids), and consequently, to the efficiency of the photosynthetic process (TAIZ; ZEIGER, 2009). These bands are essential for plant development, as they are responsible for capturing the solar energy used in photosynthesis. In this context, it was seen that treatment N4 (N = 125%) resulted in an absorption value of 93.1% in the narrow range comprising 660 and 700 nm, contrasting with the lower dose of N1 that showed 92.7% absorption in the same range, thereby reflecting a lower capacity for absorbing energy for use in the photosynthetic process.

For the treatments fertilised with nitrogen, a peak of maximum reflectance in the green can be seen between 550 and 570 nm, a slight inflection point around 570 nm, marked absorption in the red region (680 nm), with a sharp rise extending from 700 to 730 nm, called the red-edge. This behaviour agrees with that found by Zhao, Li and Qi (2005) studying the N content of cotton leaves. According to the authors, the results suggested that the applicable central wavelengths were relatively stable between the 680 and 730 nm bands. In the present study, a reflectance peak was seen in the NIR (730 nm) that developed into a short plateau of maximum reflectance (76.0%) between 788 and 897 nm.

In the NIR, it was found that the control plants subjected to a total absence of nitrogen (Tn) presented the lowest median reflectance values in the analysis, never exceeding 66% reflected energy in this band. On

the other hand, the highest factors were found under maximum fertilisation (N4), triggering values of 77%, the highest values throughout the range. Such an increase in reflectance triggered by nitrogen is related to the cellular structure of cotton leaves. Spongy mesophiles are responsible for spreading the radiation from this region of the spectrum (LIU *et al.*, 2015); therefore, the greater the volume of these vacant spaces, the greater the reflectance in the NIR.

In the SWIR region (1300 to 2500 nm) (MOREIRA, TEIXEIRA; GALVÃO, 2014), the water absorption bands located near 950, 1150, 1450, 1950 and 2350 nm (GIRARD; GIRARD, 2003) are visible in the reflectance curves of the vegetation, mainly as they are the principal features affecting these curves. It can be seen that the absorption peaks at 950 and 1150 nm are relatively small, while the nuclei at 1450 and 1950 nm become quite marked as more water is present. At 980 nm and 1198 nm, there was a rise of 13.3% and 11.7% respectively between treatment N4 and the control. The control (Tn) showed the highest reflectance factors (11.8% and 4.3%) at 1450 and 1950 nm, indicating the lower proportion of water in this tissue. However, the analysis showed that treatment N4 was only 1.8% lower in these bands for water absorption, pointing to greater water reserves under this treatment, but with some discrepancies. This suggests that these bands are not so determinant in characterising moisture as are the nuclei at 950 and 1150 nm.

In the visible spectrum, the dose of KCl did not determine the green coloration of the cotton leaves in the 550 nm band (Figure 03), as did nitrogen (Figure 02). However, it was also found that yellowing of the leaf tissues was greater in treatment K1, reaching the highest factors in the 570 nm band (NOVO, 2008).

In addition, treatment K1 obtained the highest reflectance factor (7.2%) in the red region (620-750 nm), in contrast to treatments K3 and K4 (K=125%), where the reflectance factors were 6.6%, demonstrating the greater efficiency of chlorophyll for absorbing energy in this region. Comparing macronutrients shows factors 8% lower at the inflection point at 550 nm, and 7% lower in the more-continuous band of the NIR (780 to 939 nm).

In the infrared band, it can be seen that treatments K1 and K3 presented the most-similar median reflectance factors of those under study, however, these were higher in treatment K3 throughout range corresponding to the NIR (700 to 1300 nm). In the same region, lower spectral factors were clearly seen in treatment K4 (K = 125%), approaching the behaviour of the control, and suggesting that an overdose of potassium is more harmful to the mesophilic structure than the sub-fertilisations under evaluation (K1 and K2). For the absorption peaks at 980 nm and 1198 nm

there was an increase of 10.3% and 15.1% respectively between treatment K3 and the control.

Fertilisation at 50% of the potassium requirement (K1) also showed a lower absorption in the 1400-1500 nm region, while treatments K3 and K4 showed similar factors, suggesting that the water present in the leaf tissue was not modified because of the overdose, but that the supply of less fertiliser than required triggered a marked restriction of this parameter.

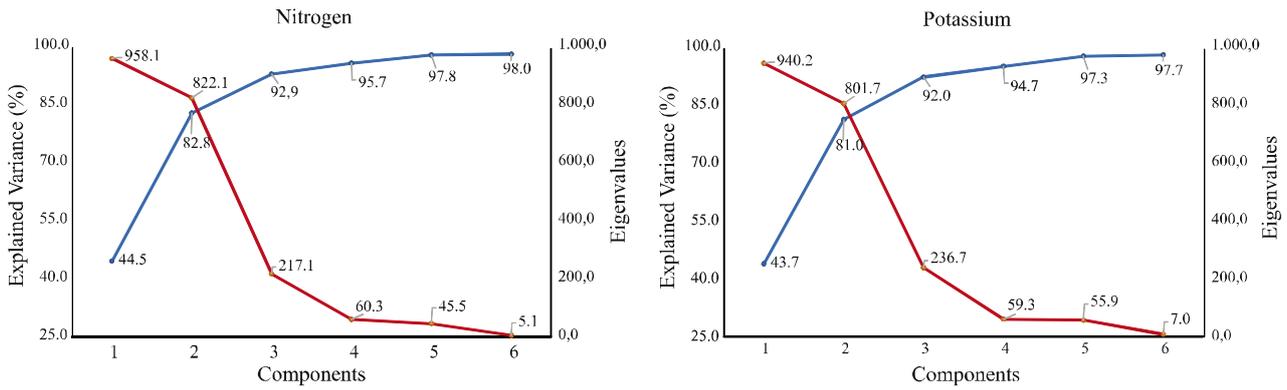
The assumptions of partial correlations and sphericity were verified by the Kaiser-Meyer-Olkin test (KMO), with values of 0.95 for N and 0.92 for K, both higher than the limit allowed by Pallant (2007), as well as the statistically significant ($p < 0.05$) Bartlett Test of Sphericity (BTS), both of which explained the adjustment of the hyperspectral data to the Factor Analysis. Corroborating Liu *et al.* (2017), hierarchical behaviour was initially seen between the PCs, where each lower-order factor represented greater variation than did subsequent factors.

The principal component analysis (PCA) for each macronutrient generated five factors with eigenvalues greater than 1% of the variation in the treatments with nitrogen and potassium. Whereas, in the Scree-Plot (Figure 4), it can be seen that 93% and 92% of the total variance explained by the factors of these electromagnetic spectra were captured by the first three principal components extracted in the fertilisation with N and K respectively. The remaining PCs were less efficient in explaining the variance of the original reflectance factors as they were noisy or multicollinear, and could therefore be discarded without impairing the analysis (MIRZAIE *et al.*, 2014).

With a view to a better interpretation of the factors, a varimax orthogonal rotation of the axes was carried out. Given the high percentage of variance explained by the first principal components extracted, it can be assumed that three components are sufficient to represent the different sets of data (YANG *et al.*, 2016), however, for the purpose of scientific research, the maximum explanation achieved by the variables was maintained.

The factor loadings of each wavelength demonstrate the correlation between the bands and their respective PC. This relationship is important to identify which bands stand out for better explaining the PC, since the higher the loading, the greater the representativeness of the band in the Principal Component. It is accepted that the values might range from 1 to -1, however, when stipulating the parameters of the PCA, it was decided not to present loadings of less than ± 0.33 , as this value corresponds to a threshold of one third representativeness. Therefore, the higher the loadings, the greater the representativeness of a wavelength in that component.

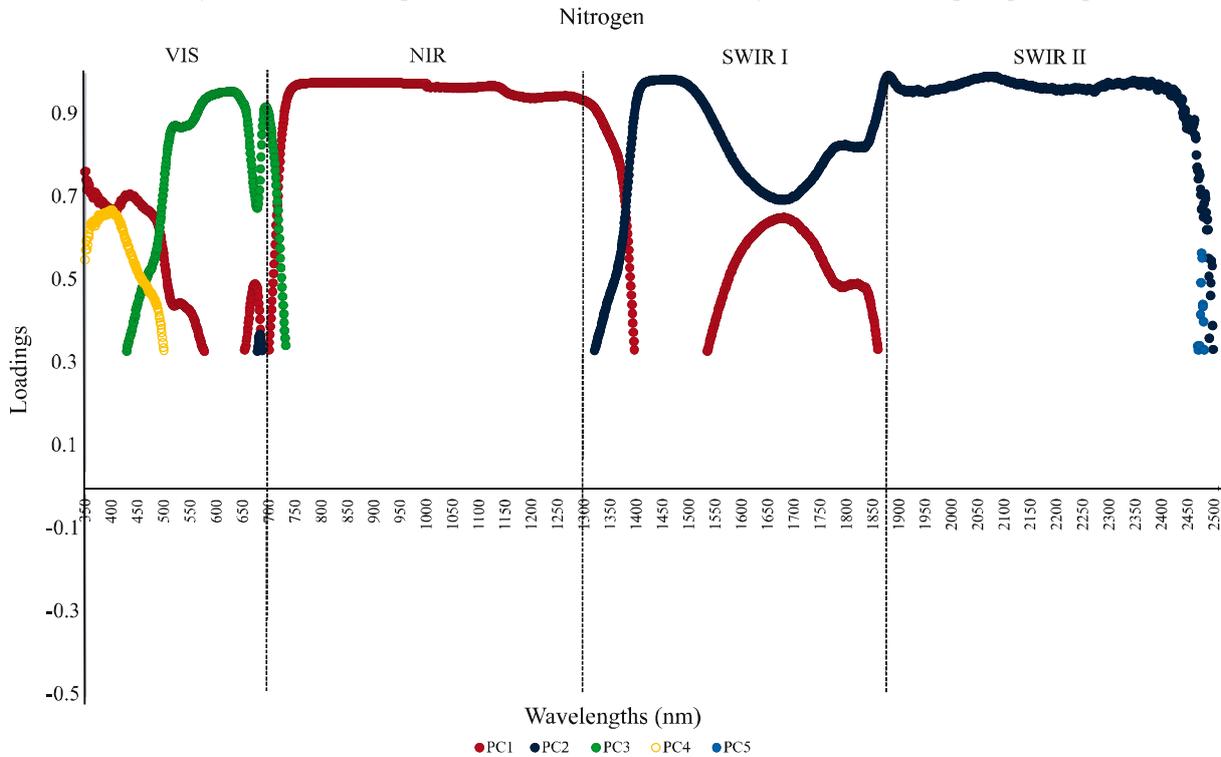
Figure 4 - Explained variance by Eigenvector and Eigenvalue as a function of the number of components, for reflectance data in cotton leaves for nitrogen (n = 80) and potassium (n = 80)



As can be seen in the case of N (Figure 5), principal component 1, which maintains most of the initial behaviour of the data (44.5% of explained variance), is mainly defined by the reflectances between 700 nm and 1400 nm, the latter being the most expressive. This means that PC1 only began to have a strong influence at the red-edge (710 nm), and remained at this representativeness throughout the entire NIR, up to the first water absorption band at 1400 nm.

It is worth noting that although hyperspectral data were used to discriminate the wavelengths that most correlated with the observed oscillations in fertilisation, the aim was to observe the same set of data from a different point of view, one capable of capturing the similarities between the original wavelengths, and that would be useful in representing the same data structure in a more concise and physically grounded way. As such, the grouping of input variables into new entities, more comprehensive

Figure 5 - Factor loadings of the reflectance spectrum in cotton fertilised with nitrogen, for the first five principal components extracted



and with less causal dispersion, allowed the effect of the different fertilisations on the leaves to be visualised.

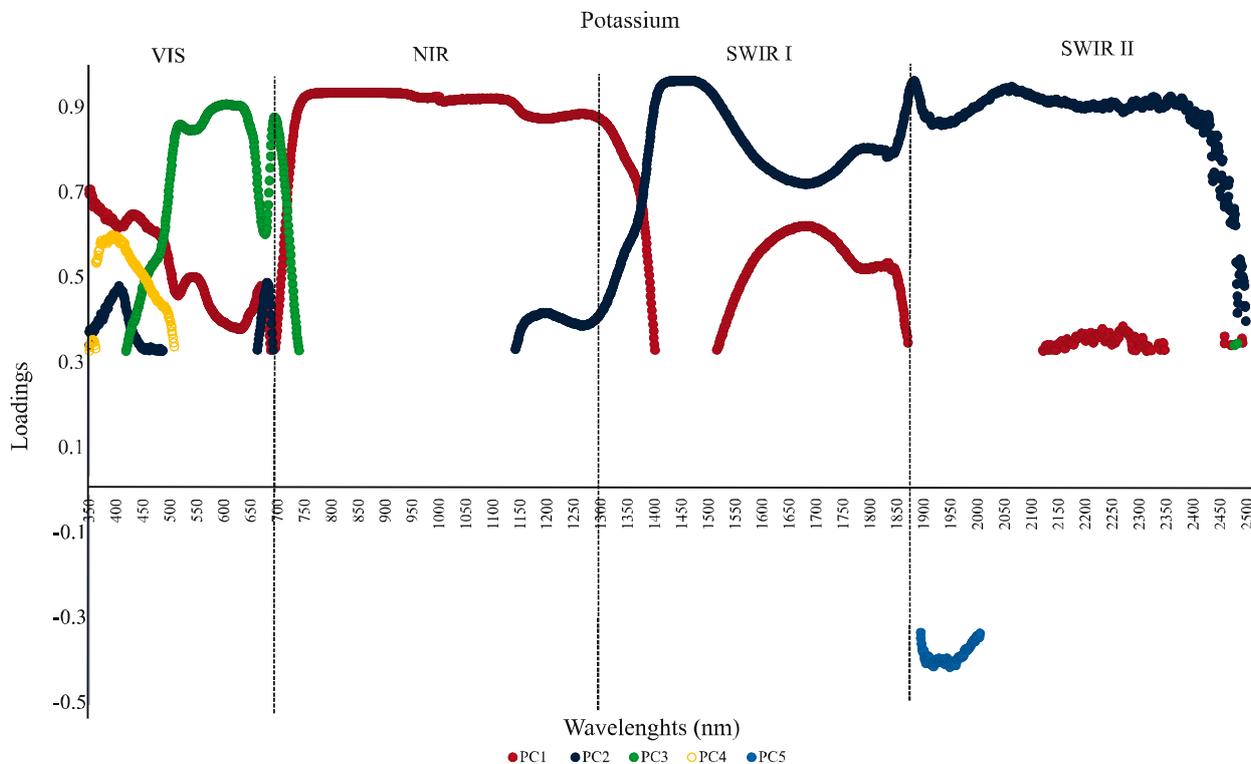
Indeed, for both macronutrients the treatments were better differentiated in the infrared region (710 nm to 1300 nm). This same PC1 was less influential in the visible band and in the intervals between the water absorption bands mentioned above, but nonetheless significant (>0.33). With less representativeness, the regions from 350 to 600 nm (probably related to strong absorption in the blue band) and the wavelengths from 1550 to 1850 nm should also be noted.

On the other hand, PC2 was the main component of the shortwave infrared band (SWIR I and II), where, as per Jensen (2011), the water absorption bands and indicators of percentage dry matter are concentrated. The third component (PC3) was seen in the visible, especially in the green (550 nm), yellow (600 nm) and red (700 nm), with factor loadings greater than those of PC1 for this region. The behaviour of PC4 was less marked, showing weightings in the violet (400 nm) and blue (470 nm), and PC5 at 2480 nm. In the red region (670 nm) and the red-edge (680-780 nm), the three components showed low explanatory potential, however, the original variables showed greater eigenvalues when explaining the data by PC3 (eigenvalue = 0.68).

In fertilisations with potassium, the first component (PC1) proved to predominate in the Visible, NIR and SWIR I to a lesser extent than nitrogen, and was still evident in the SWIR II (Figure 06). The visible band of the N and K treatments, especially the wavelengths between green (550 nm) and red (670 nm), were better represented when grouped in PC3. Unlike the results found by Sun *et al.* (2017), PC2 was more significant in the visible region for vegetation spectra under the potassium treatments (Figure 6), despite being found around 700 nm for nitrogen (Figure 5), typical absorption bands of chlorophylls and carotenoids. PC2 became gradually more evident from 1150 nm, with a marked reduction in explanatory power between 1880 and 2050 nm.

The fourth and fifth components showed representativeness in the more specific wavelengths of the spectral profile, as they explained wavelengths in the visible (400 nm) and the second water absorption bands (1900 to 2000 nm) respectively. This last PC, although not very significant, showed negative factor loadings in this band, and was able to capture 16% of the occurred variance at the highest or lowest concentration of potassium applied. This result is useful, as it suggests two components (PC2 and PC5) that are sensitive to the changes that occur in this band of interest. In the SWIR II, it was seen that PC2 in nitrogen (Figure 5) demonstrated a better ability to

Figure 6 - Factor loadings of the reflectance spectrum in cotton fertilised with potassium, for the first five principal components extracted



explain its behaviour in the water absorption bands, since little oscillation was demonstrated in its factor loadings. However, the bands that comprised the second factor in potassium, lost explanatory power at 1950 nm.

One interesting comparison between factor loads shows that the macronutrient, whether nitrogen or potassium, did not drastically reorder the wavelengths of each component, probably because they are the two macronutrients most required by cotton, among various other crops, and because they play roles that maintain the activity of chlorophyll, which acts both in photosynthetic metabolism and in greening the leaves, recognised by PC1 and PC3 generated by the PCA. In general, reflectances in the NIR (800 nm to 1300 nm) and in the visible (400 nm to 700 nm) are continually associated in the literature with changes in the cell structure of the mesophile (MIPHOKASAP *et al.*, 2012) and in the levels of chlorophyll (INOUE *et al.*, 2016). The relevance of the infrared to PC1 was also reported by Yang *et al.* (2016) in rice. PC1 expressed well the variations in the total reflectance of the leaves (JENSEN, 2011), as it had high loading values at the less absorbed wavelengths. This component is usually associated with brightness (MOREIRA; TEIXEIRA; GALVÃO, 2014) and, as such, has little use in the quantitative discrimination of this study.

CONCLUSIONS

1. The highest reflectance levels measured at 550 nm were 19% (CV = 11.8%) and 16% (CV = 9.68%) for plants fertilised with N and K respectively;
2. Under these laboratory conditions, in the NIR band (700-1300 nm), the factors did not exceed 77% reflectance in the treatments with N and 71% in the treatments with K;
3. For the water content of the leaf tissue, greater variations at 1198 nm were found for potassium, on average of 15.1%, while the effect of the nitrogen was better identified at 980 nm (13.3%);
4. PCA showed that the largest part of the data variance could be explained by the wavelengths located in the NIR and SWIR I, irrespective of which macronutrient was deficient;
5. Fertilisation with nitrogen and potassium caused significant changes in the spectral reflectance profile of cotton, where the greatest difference between the doses of N and K were seen at 790 and 1198 nm;
6. Specifically, the bands between 550 and 700 nm and close to the nuclei of 1390 and 1880 nm proved to be

the most promising for complementing the explanatory power in differentiating the nutrient levels of N and K in the cotton crop.

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